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HOUGH COMPONENTS OF WATER VAPOUR HEATING

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Hough components of water vapour heating

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Abstract

Formulae are derived for the Hough components and mean rate of insolational heating by water vapour absorption in an atmosphere with cloud-related scattering properties. Global models of specific humidity and cloud amount are adopted for the months of January, April, July and October and used in conjunction with adopted values of surface albedo, absorption coefficients and scattering parameters to evaluate diurnal and semi-diurnal components of heating for migrating modes. The inclusion of cloud scattering has the notable effect of nearly doubling heating rates at 8 km altitude and of halving values near the surface. A number of non-migrating components associated with the principal diurnal and semi-diurnal modes have also been evaluated.

CONTENTS

1. Introduction

Insolational heating due to water vapour absorption was introduced by Siebert (1961) as a source of tidal excitation. Formulations of the diurnal and semi-diurnal components of Siebert's model of heating have been given in terms of Hough functions by Lindzen (1967), Chapman and Lindzen (1970), and Lindzen and Hong (1974). In Siebert's model, heating rates decrease with height as the cube root of atmospheric pressure, and above 10 km have been shown to be greatly in excess of those based on more realistic upper troposphere water vapour densities (Groves, 1977; Forbes and Garrett, 1978).

The present paper undertakes a re-evaluation of diurnal and semi-diurnal Hough components with attention given to the effects of clouds: account will also be taken of longitudinally dependent terms.

2. Water vapour heating with clear skies

In terms of hemispherically averaged downward and upward fluxes $F^{\downarrow}(z)$, $F^{\uparrow}(z)$ of solar radiation incident on a horizontal surface at height z, the heating rate per unit mass of atmosphere is

$$J_a = \frac{1}{\rho}\frac{d}{dz}\left(F^{\downarrow} - F^{\uparrow}\right) \tag{2.1}$$

where ρ is air density.

With clear skies the absorption A of the downward flux is defined by

$$F^{\downarrow} = \cos\zeta \, S_o (1 - A) \qquad (2.2)$$

where S_o is the solar flux outside of the atmosphere and ζ is solar zenith angle. S_o is taken as 0.1353 W cm^{-2} (Thekaekara, 1973) with an inverse square dependence on the Sun-Earth distance.

For water vapour, various empirical formulae have been devised which relate A to the STP path length of water vapour y. With y in cm units, Lacis and Hansen (1974) give

$$A(y) = 2.9y/[(1 + 141.5y)^{0.635} + 5.925y] \qquad (2.3)$$

For $10^{-2} \leq y \leq 10$ cm, (2.3) lies within 1 per cent of the absorption curve of Yamamoto (1962) which in turn was derived from the low resolution spectral measurements by Howard et al. (1956) of the major water vapour bands.

For the downward flux the optical path may be related to the water vapour amount w (in cm) above height z by

$$y = M w \qquad (2.4)$$

where M is a magnification factor

$$M = 35/(1224\cos^2 S + 1)^{\frac{1}{2}} \tag{2.5}$$

A significant dependence of water vapour absorption on pressure p complicates the introduction of (2.4) into (2.3). We follow Lacis and Hansen (1974) and replace w by an effective water vapour amount above height z defined by

$$w = \int_z^\infty q\,\rho \left(\frac{p}{p_o}\right)^n \left(\frac{T_o}{T}\right)^{\frac{1}{2}} dz \tag{2.6}$$

where q is specific humidity and n is chosen to scale w to the value that would give the same absorption at STP (p_o = 1013 mb, T_o = 273 K) as the actual optical path. $(T_o/T)^{1/2}$ has likewise been introduced to allow for a smaller temperature dependence.

To evaluate (2.6), we assume a constant lapse rate Γ, then

$$T/T_o = (p/p_o)^{\Gamma R_M/g} \tag{2.7}$$

where g is acceleration due to gravity and R_M is the gas constant for air. By (2.7) and the hydrostatic equation, (2.6) becomes

$$w = \frac{p_o}{g}\int_0^{\eta} q\,\eta^c\,d\eta \tag{2.8}$$

where

$$c = n - \Gamma R_M/2g \tag{2.9}$$

$$\eta = p/p_o \tag{2.10}$$

In subsequent calculations we take n = 0.75 and $\Gamma R_M/g$ = 0.19: Siebert (1961) took n = 1 and $\Gamma R_M/g$ = 0, i.e. the temperature correction was omitted. Fig. 13 of Lacis and Hansen (1974) shows that calculated heating rates in the middle troposphere are insensitive to the choice of n between 0 and 1, the effect of increasing n being to reduce heating in the upper troposphere and increase it slightly in the lower troposphere: the relative effect of n on heating rates is therefore primarily of importance in the upper troposphere. A similar conclusion was reached by McDonald (1960).

Corresponding to (2.2), we define the absorption of the upward flux A' by

$$F^{\uparrow} = R \cos\zeta\, S_o\,(1 - A') \tag{2.11}$$

where R is the albedo of the reflecting surface. An effective

optical path y' is then defined by

$$A(y') = A' \qquad (2.12)$$

A' is obtained by adopting an approximate expression for y'

$$y' = M w_t + \tfrac{5}{3}(w_t - w) \qquad (2.13)$$

where w_t is the total water vapour amount above the reflecting surface and 5/3 is an average magnification factor for diffuse radiation.

By (2.2) to (2.4), (2.6), (2.7), (2.9) to (2.13) we obtain from (2.1) the heating rate under clear skies J_{al} as

$$J_{a1} = q\,\eta^{c} \cos\zeta\; S_0 \left[M A_1(y) + \tfrac{5}{3} R A_1(y') \right] \qquad (2.14)$$

where

$$A_1 \equiv \frac{dA}{dy} = 2.9\,\frac{0.635 + 0.365\,Y}{(Y^{0.635} + 5.925\,y)^2\,Y^{0.365}} \quad (\mathrm{cm}^2/\mathrm{g}) \qquad (2.15)$$

$$Y = 1 + 141.5\,y \qquad (2.16)$$

3. Heating in a cloudy atmosphere

In the presence of clouds heating rates are again obtainable from (2.1) but the problem of deriving $F^{\downarrow}$ and $F^{\uparrow}$ is complicated by the introduction of scattering. The possibility of dealing with cloud distributions and cloud microphysics in detail is practically excluded by the lack of adequate data on a global scale and by the need to evaluate heating profiles at many latitudes and longitudes with modest computing times. The problem is therefore considered of devising a heating formula based on a distribution of scattering properties which with a few suitably chosen parameters can be taken to approximate time-averaged atmospheric conditions, in particular monthly mean conditions.

The distribution of clouds is specified by cloud amount as a function of latitude and longitude; and within any cloud-covered area scattering properties are assigned to all heights in terms of the fraction f of forward scattered radiation in a scattering event and a scattering coefficient σ based on effective water vapour density. No account is taken of cloud layer structure, its time-averaged distribution being replaced notionally by a continuous height distribution of scattering properties defined in terms of σ and f.

Evaluation of radiation fluxes is based on the two-stream

approximation to the radiative transfer equation in which the parameters f and ω are taken to be independent of height and solar zenith angle, where ω is the single scattering albedo

$$\omega = \sigma/(\sigma + k) \tag{3.1}$$

k being a water vapour absorption coefficient based on effective water vapour density. The assumption that ω is independent of height is appropriate to monochromatic radiation, but not to the part of the solar spectrum that interacts with water vapour. A way out of this difficulty is taken by representing the dependence of absorption on optical path by a best fit series of exponential terms

$$A(y) = 1 - \sum_i a_i e^{-k_i y} \tag{3.2}$$

where $\sum_i a_i = 1$. This procedure is equivalent to approximating the interacting spectrum by a series of monochromatic radiations each having an incident flux $a_i S_o$.

For the i-th component of flux the radiative transfer equations are taken in the form presented by Houghton (1977)

$$\frac{dF^{\downarrow}}{d\chi^{*}} + F^{\downarrow} = \omega\left[f F^{\downarrow} + (1-f) F^{\uparrow} \right] \tag{3.3}$$

$$-\frac{dF^{\uparrow}}{d\chi^{*}} + F^{\uparrow} = \omega\left[(1-f) F^{\downarrow} + f F^{\uparrow} \right] \tag{3.4}$$

where the suffix i has been omitted and $d\chi^*$ is an increment of optical depth defined by

$$d\chi^{*} = \tfrac{5}{3}\,(\sigma + k)\,dw \tag{3.5}$$

the factor 5/3 being introduced as an average *magnification* factor appropriate to diffuse radiation. Boundary conditions

$$\begin{aligned} F^{\downarrow} &= \cos\zeta\, S_0 \qquad && (\chi^{*} = 0) \\ F^{\uparrow}/F^{\downarrow} &= R \qquad && (\chi^{*} = \chi^{*}_{0}) \end{aligned} \tag{3.6}$$

are introduced where R is surface albedo and χ^*_0 is the value of χ^* at the surface. The required solutions are

$$F^{\uparrow}/\cos\zeta\, S_0 = \mathrm{sh}\,(\xi_0 + \beta' - \xi)/\mathrm{sh}\,(\xi_0 + \beta) \tag{3.7}$$

$$F^{\downarrow}/\cos\zeta\, S_0 = \mathrm{sh}\,(\xi_0 + \beta - \xi)/\mathrm{sh}\,(\xi_0 + \beta) \tag{3.8}$$

where by (3.5)

$$\xi = \alpha \chi^{*} = k' w \tag{3.9}$$

$$\alpha = (1-\omega)^{\frac{1}{2}}(1+\omega-2\omega f)^{\frac{1}{2}} \tag{3.10}$$

$$k' = \frac{5}{3}\alpha(\sigma + k) \tag{3.11}$$

$$\beta = \frac{1}{2}\ln\left\{[1+\alpha-\omega f - R\omega(1-f)]/[1-\alpha-\omega f - R\omega(1-f)]\right\} \tag{3.12}$$

$$\beta' = \beta + \frac{1}{2}\ln[(1-\alpha-\omega f)/(1+\alpha-\omega f)] \tag{3.13}$$

In the special case R = 0, it follows from (3.12) and (3.13) that $\beta' = 0$.

By (2.6) to (2.10) and (3.7) to (3.9), we obtain from (2.1) the heating rate in a cloudy atmosphere J_{a2} as

$$J_{a2} = q\,\eta^{c}\cos\zeta\, S_0\, Z \tag{3.14}$$

where

$$Z = \sum_i \left\{\alpha k'[ch(\xi_0+\beta-\xi) - ch(\xi_0+\beta'-\xi)]/sh(\xi_0+\beta)\right\}_i \tag{3.15}$$

January	Longitude W								
	180	160	140	120	100	80	60	40	20
35 N									
400	0.30	0.20	0.25	0.20	0.20	0.25	0.30	0.30	0.25
500	0.90	0.80	0.60	0.50	0.50	0.60	0.70	0.80	0.60
700	2.00	2.20	1.90	1.60	1.80	1.90	2.00	2.10	2.10
850	4.00	4.00	3.80	2.70	2.50	3.20	4.50	5.30	4.10
1000	7.50	8.20	7.50	5.50	0.00	4.20	6.50	8.50	8.00
30 N									
400	0.35	0.30	0.40	0.30	0.30	0.40	0.40	0.25	0.20
500	1.00	0.85	0.90	0.70	0.70	0.80	0.70	0.55	0.45
700	2.30	2.40	2.20	1.90	2.00	2.40	2.20	2.10	1.50
850	5.50	5.50	4.60	3.50	3.80	4.70	5.50	6.10	3.40
1000	9.50	9.70	9.20	6.70	0.00	6.20	9.00	9.50	8.60
25 N									
400	0.40	0.35	0.45	0.55	0.40	0.35	0.35	0.20	0.20
500	1.10	0.85	0.95	1.10	0.90	0.75	0.70	0.50	0.30
700	2.40	2.70	2.50	2.20	3.00	2.90	2.50	1.70	0.90
850	6.60	6.80	5.70	4.50	5.00	7.00	6.70	6.00	2.90
1000	11.20	11.00	10.00	9.00	7.50	10.50	11.80	11.00	8.50
20 N									
400	0.50	0.40	0.55	0.60	0.45	0.40	0.35	0.20	0.30
500	1.20	0.90	1.20	1.45	1.05	0.80	0.75	0.45	0.50
700	2.70	2.90	2.80	2.80	4.00	3.70	2.50	1.40	0.80
850	7.50	8.00	6.80	6.00	6.80	9.30	7.80	5.50	2.60
1000	12.60	12.20	11.20	10.30	11.00	14.00	14.00	12.50	9.00
15 N									
400	0.55	0.50	0.60	0.70	0.55	0.45	0.40	0.30	0.45
500	1.35	1.00	1.40	1.60	1.20	0.90	0.80	0.65	1.00
700	2.90	3.20	3.10	3.40	4.50	3.50	2.90	1.80	2.00
850	8.30	8.40	8.00	7.20	8.00	9.60	8.50	5.50	2.90
1000	13.50	12.80	12.00	11.70	12.70	16.20	15.00	13.60	10.00
10 N									
400	0.60	0.60	0.70	0.75	0.65	0.55	0.50	0.65	0.76
500	1.50	1.25	1.60	1.70	1.40	1.20	1.00	1.00	1.15
700	3.30	3.60	3.90	4.30	5.30	4.00	4.00	3.00	2.70
850	9.00	8.80	8.70	8.40	9.20	9.80	10.00	6.70	4.20
1000	14.50	13.60	13.00	13.00	14.00	16.10	15.00	15.50	14.00
5 N									
400	0.65	0.70	0.77	0.85	0.75	0.70	0.70	0.80	0.80
500	1.55	1.45	1.70	1.85	1.70	1.80	1.70	1.50	1.30
700	3.90	3.90	5.00	5.20	5.80	6.70	6.50	4.00	3.50
850	9.80	9.50	9.60	9.70	10.10	10.10	11.30	8.50	6.80
1000	16.00	14.60	13.90	14.10	14.70	15.80	16.20	16.30	16.50
0									
400	0.75	0.80	0.90	0.95	0.90	0.90	0.90	0.80	0.75
500	1.60	1.60	1.80	1.90	2.00	2.40	2.50	1.70	1.30
700	4.40	4.40	6.00	6.40	7.20	8.20	8.00	4.80	4.20
850	10.10	9.80	10.30	10.40	10.68	10.90	12.20	10.70	8.50
1000	16.80	15.20	14.70	14.90	15.40	15.00	17.20	16.50	16.80

Table 1. Longitudinal cross-sections of specific humidity in g/kg for January, April, July and October at latitudes from 35 N to 35 S and 400, 500, 700, 850, and 1000 mb

January	Longitude W								
	180	160	140	120	100	80	60	40	20
0									
400	0.75	0.80	0.90	0.95	0.90	0.90	0.90	0.80	0.75
500	1.60	1.60	1.80	1.90	2.00	2.40	2.50	1.70	1.30
700	4.40	4.40	6.00	6.40	7.20	8.20	8.00	4.80	4.20
850	10.10	9.80	10.30	10.40	10.60	10.90	12.20	10.70	8.50
1000	16.80	15.20	14.70	14.90	15.40	15.00	17.20	16.50	16.80
5 S									
400	0.75	0.85	1.00	1.10	1.10	1.10	1.00	0.75	0.60
500	1.50	1.70	2.00	2.10	2.30	3.00	2.80	1.70	1.20
700	5.10	4.70	6.20	7.20	8.10	8.00	7.60	4.10	4.10
850	10.10	10.20	11.00	11.00	11.00	11.30	12.30	11.00	8.70
1000	18.00	16.20	15.50	15.60	16.10	15.80	17.80	16.10	15.80
10 S									
400	0.80	0.85	1.10	1.20	1.20	1.20	1.10	0.75	0.40
500	1.60	1.85	2.20	2.45	2.80	3.20	2.90	1.60	1.00
700	6.00	5.30	6.60	7.20	8.10	6.40	6.70	4.30	3.70
850	10.20	10.60	11.10	11.20	11.50	11.00	12.00	10.00	7.90
1000	18.20	16.60	16.10	16.10	16.10	15.80	17.00	0.00	13.60
15 S									
400	0.80	0.85	1.10	1.20	1.20	1.10	1.00	0.70	0.40
500	1.55	1.80	2.30	2.50	2.80	2.70	2.60	1.50	0.85
700	6.10	5.10	6.30	6.50	6.70	5.20	6.20	4.00	3.20
850	10.20	10.50	11.10	11.10	11.00	10.00	12.00	9.30	7.50
1000	18.20	17.10	16.60	16.40	16.20	16.20	16.00	0.00	12.80
20 S									
400	0.80	0.85	1.10	1.10	1.00	0.80	0.85	0.60	0.30
500	1.60	1.55	2.10	2.20	2.20	1.80	1.95	1.45	0.75
700	6.00	4.80	5.90	5.80	5.20	4.20	6.20	4.00	2.80
850	10.10	10.20	10.80	10.50	10.20	8.40	12.00	8.20	6.80
1000	17.20	16.50	16.30	16.20	16.10	13.00	13.20	0.00	12.00
25 S									
400	0.65	0.70	0.85	0.85	0.75	0.60	0.75	0.50	0.25
500	1.50	1.40	1.75	1.80	1.70	1.40	1.60	1.20	0.60
700	3.80	3.80	4.00	4.10	3.90	3.20	5.50	3.50	2.30
850	9.10	8.90	9.20	9.00	8.60	6.60	11.30	7.40	6.20
1000	15.20	15.20	15.20	15.00	14.30	11.20	13.80	13.20	11.10
30 S									
400	0.60	0.60	0.60	0.60	0.55	0.45	0.60	0.40	0.20
500	1.40	1.30	1.20	1.35	1.30	1.00	1.40	0.90	0.45
700	2.90	2.00	3.00	3.00	2.70	2.00	3.90	2.60	1.80
850	7.30	7.30	7.00	7.00	6.20	5.30	9.50	6.20	5.20
1000	12.50	12.50	13.00	12.50	11.90	9.70	11.50	11.30	10.20
35 S									
400	0.55	0.60	0.65	0.70	0.65	0.60	0.50	0.25	0.20
500	0.80	0.80	0.90	0.95	0.90	0.85	1.10	0.50	0.40
700	1.80	1.80	1.90	2.00	1.90	1.80	2.30	1.90	1.80
850	5.70	5.80	6.30	6.30	5.00	4.30	6.10	4.80	4.10
1000	10.20	10.20	10.40	10.30	9.50	8.20	10.30	10.00	9.30

Table 1. (continued) <u>Zero values are entered for 1000 and 850 mb levels that are below the Earth's surface for more than 10^{o} of longitude</u>

January	Longitude E								
	0	20	40	60	80	100	120	140	160
35 N									
400	0.20	0.30	0.25	0.25	0.25	0.40	0.40	0.25	0.30
500	0.55	0.55	0.55	0.60	0.50	0.50	0.40	0.45	0.50
700	2.00	1.90	2.10	1.80	1.80	1.50	0.80	1.00	1.70
850	2.50	4.20	2.70	2.00	0.00	0.00	1.50	2.50	3.60
1000	5.50	5.50	6.00	0.00	0.00	0.00	1.90	2.80	5.50
30 N									
400	0.20	0.20	0.25	0.30	0.30	0.50	0.60	0.35	0.40
500	0.45	0.50	0.50	0.65	0.60	1.00	0.80	0.60	0.65
700	1.00	1.20	1.00	1.90	1.80	2.00	1.90	2.00	2.20
850	0.90	3.40	1.90	3.00	0.00	0.00	2.50	4.20	5.30
1000	4.50	5.80	5.00	0.00	0.00	0.00	3.50	5.50	7.80
25 N									
400	0.20	0.23	0.25	0.35	0.40	0.65	0.55	0.45	0.42
500	0.30	0.40	0.50	0.70	0.80	1.30	1.00	1.00	0.80
700	0.80	0.90	1.00	2.50	2.40	4.00	2.70	2.60	2.80
850	0.90	1.90	1.90	4.00	3.80	4.30	4.60	5.80	7.00
1000	3.50	0.00	7.50	8.00	6.00	6.00	5.50	8.00	11.00
20 N									
400	0.25	0.20	0.30	0.35	0.50	0.70	0.45	0.60	0.50
500	0.60	0.40	0.60	0.70	1.00	1.50	0.90	1.30	1.00
700	1.20	1.00	2.50	2.60	3.10	4.60	3.30	3.20	3.20
850	1.40	1.70	4.00	5.30	5.00	6.00	6.70	8.20	8.30
1000	3.80	0.00	10.00	8.20	8.80	9.50	8.70	12.60	13.30
15 N									
400	0.45	0.35	0.40	0.45	0.60	0.80	0.55	0.80	0.60
500	1.10	0.50	0.85	0.85	1.40	1.80	1.30	1.60	1.30
700	2.80	2.50	3.10	3.60	3.70	5.20	4.00	3.80	3.80
850	2.00	2.00	5.90	6.60	6.40	8.30	8.60	9.50	9.30
1000	3.90	6.00	0.00	11.00	12.00	12.80	12.00	15.50	15.00
10 N									
400	0.65	0.60	0.55	0.60	0.85	0.95	1.00	0.95	0.80
500	1.30	1.10	1.20	1.40	1.75	2.05	2.00	2.00	1.70
700	3.60	3.40	4.30	4.60	4.30	5.70	5.40	5.00	4.50
850	5.90	5.50	9.00	8.60	8.20	9.90	9.70	10.70	10.40
1000	9.00	13.00	0.00	15.50	14.00	14.00	14.50	17.10	16.60
5 N									
400	0.80	0.75	0.70	0.80	1.00	1.15	1.30	1.20	1.00
500	1.50	1.85	1.80	1.90	2.10	2.60	2.70	2.40	2.10
700	4.70	4.40	6.40	5.80	5.80	6.40	6.30	6.20	5.30
850	9.30	9.00	11.00	10.50	10.00	10.50	10.80	11.10	11.10
1000	18.00	16.00	19.00	18.00	16.00	16.00	16.00	18.20	17.80
0									
400	0.95	1.25	0.85	0.95	1.10	1.40	1.50	1.35	1.20
500	2.00	3.10	2.20	2.10	2.30	2.90	3.10	2.80	2.30
700	6.10	6.80	7.90	7.10	6.60	7.00	6.90	6.80	6.20
850	10.50	12.00	12.10	11.80	10.90	11.00	11.10	11.30	11.40
1000	18.30	18.10	19.90	18.80	18.10	16.80	17.30	18.30	18.20

Table 1. (continued)

January	Longitude E								
	0	20	40	60	80	100	120	140	160
0									
400	0.95	1.25	0.85	0.95	1.10	1.40	1.50	1.35	1.20
500	2.00	3.10	2.20	2.10	2.30	2.90	3.10	2.80	2.30
700	6.10	6.80	7.90	7.10	6.60	7.00	6.90	6.80	6.20
850	10.50	12.00	12.10	11.80	10.90	11.00	11.10	11.30	11.40
1000	18.30	18.10	19.90	18.80	18.10	16.80	17.30	18.30	18.20
5 S									
400	0.90	1.70	0.95	1.05	1.20	1.45	1.60	1.50	1.40
500	2.20	4.00	2.70	2.30	2.40	3.00	3.40	3.00	2.50
700	6.20	9.10	8.20	8.10	7.20	7.10	7.10	7.00	6.60
850	10.50	12.20	12.20	12.10	11.50	11.00	11.20	11.50	11.70
1000	17.80	18.00	20.10	19.00	18.20	17.50	17.80	18.50	18.50
10 S									
400	0.90	2.10	1.10	1.10	1.20	1.40	1.55	1.55	1.50
500	2.00	4.10	2.80	2.70	2.70	2.80	3.10	2.80	2.50
700	4.80	7.90	8.40	8.10	7.80	7.40	7.20	7.10	7.00
850	9.30	12.50	12.50	12.10	11.50	10.60	11.10	11.50	12.00
1000	15.20	16.00	19.90	18.00	17.90	16.80	17.80	18.50	18.00
15 S									
400	0.75	1.60	1.25	1.10	1.20	1.35	1.45	1.50	1.45
500	1.50	3.60	2.70	2.40	2.50	2.60	2.90	2.80	2.50
700	3.70	6.90	8.10	7.00	7.20	7.20	6.80	6.60	7.10
850	7.70	11.20	12.20	11.70	10.80	10.20	10.80	11.10	12.00
1000	13.50	0.00	19.30	17.00	16.10	16.20	16.30	16.20	17.00
20 S									
400	0.50	1.70	1.20	0.90	1.10	1.20	1.20	1.30	1.25
500	1.00	2.80	2.45	2.10	2.30	2.40	2.50	2.40	2.30
700	2.70	6.20	7.30	5.90	6.50	6.80	6.10	5.80	6.80
850	6.80	10.00	12.10	11.00	10.00	9.40	9.20	10.00	10.50
1000	12.30	0.00	18.20	15.10	14.50	15.00	16.00	14.00	15.50
25 S									
400	0.35	0.75	1.00	0.80	0.90	1.05	1.05	1.00	1.20
500	0.70	1.90	2.10	1.85	2.05	2.15	2.20	2.20	2.10
700	2.10	5.50	6.00	5.20	5.70	5.90	5.10	4.50	5.70
850	6.10	8.00	11.10	9.90	8.70	8.20	7.70	8.00	9.20
1000	11.10	0.00	17.00	13.30	12.80	13.00	0.00	11.60	14.10
30 S									
400	0.25	0.45	0.80	0.60	0.65	0.80	0.85	0.85	0.95
500	0.40	0.65	1.60	1.55	1.70	1.80	1.75	1.75	1.80
700	1.70	3.30	5.10	4.70	5.00	4.80	4.00	3.70	4.00
850	5.30	6.00	9.60	8.30	7.40	7.10	6.00	6.00	7.70
1000	9.90	10.30	13.40	11.00	10.80	10.40	0.00	10.70	12.70
35 S									
400	0.20	0.30	0.50	0.50	0.50	0.55	0.65	0.75	0.75
500	0.40	0.45	1.40	1.40	1.50	1.45	1.40	1.45	1.50
700	1.70	1.95	4.10	4.20	4.20	3.90	2.60	2.20	2.60
850	4.20	5.30	6.90	6.60	6.50	6.00	5.70	5.70	6.30
1000	8.90	9.10	10.40	9.50	9.30	8.90	7.50	10.00	11.50

Table 1. (continued)

April	Longitude W								
	180	160	140	120	100	80	60	40	20
35 N									
400	0.35	0.30	0.25	0.20	0.30	0.30	0.35	0.35	0.25
500	0.60	0.60	0.50	0.45	0.70	0.80	0.80	1.00	0.70
700	1.80	1.90	1.80	1.50	2.50	2.30	2.10	2.10	2.10
850	3.90	3.90	3.80	3.70	4.00	4.30	5.00	5.00	4.20
1000	7.80	7.50	6.70	6.30	0.00	7.80	9.50	9.50	7.90
30 N									
400	0.40	0.40	0.30	0.25	0.35	0.40	0.40	0.30	0.20
500	0.80	0.80	0.70	0.55	0.60	0.90	1.00	1.00	0.60
700	2.00	2.20	2.00	1.90	2.40	2.60	2.70	2.40	2.10
850	4.90	4.80	4.50	3.50	5.00	5.50	6.10	5.80	4.20
1000	9.50	9.00	8.00	8.00	0.00	9.50	11.50	10.50	9.00
25 N									
400	0.40	0.40	0.35	0.40	0.40	0.50	0.40	0.30	0.20
500	0.85	0.90	0.85	0.85	0.95	1.00	1.30	0.85	0.55
700	2.50	2.70	2.70	2.60	3.30	3.90	3.70	2.60	1.50
850	6.40	6.50	6.20	5.00	6.00	7.50	8.00	6.60	4.30
1000	10.50	10.50	10.00	10.60	13.30	12.50	12.80	12.00	9.50
20 N									
400	0.45	0.55	0.50	0.55	0.50	0.60	0.45	0.35	0.25
500	0.95	1.10	1.05	1.10	2.00	1.00	1.00	0.65	0.40
700	3.20	3.30	3.30	3.50	4.00	4.20	3.90	2.20	0.90
850	8.00	9.20	8.50	7.50	7.20	8.80	8.80	7.30	4.10
1000	12.50	12.10	12.00	13.30	15.00	16.00	14.50	13.70	10.50
15 N									
400	0.50	0.60	0.55	0.60	0.60	0.70	0.45	0.45	0.55
500	1.10	1.30	1.30	1.40	2.20	1.30	0.95	0.65	0.50
700	3.70	3.80	3.90	4.30	5.10	3.80	3.80	2.00	1.00
850	9.00	9.60	9.40	9.00	8.70	9.60	9.30	8.00	4.10
1000	14.00	14.00	14.00	15.10	16.70	16.40	15.20	15.00	11.80
10 N									
400	0.60	0.65	0.70	0.70	0.70	0.75	0.65	0.65	0.75
500	1.20	1.50	1.60	1.70	2.30	1.80	1.40	0.80	1.00
700	4.20	4.70	5.10	5.30	6.50	5.80	7.20	2.70	2.50
850	9.60	10.40	10.20	10.10	10.20	10.00	11.00	9.00	6.00
1000	15.50	15.50	16.00	16.30	17.90	17.50	16.50	16.30	16.20
5 N									
400	0.60	0.70	0.75	0.80	0.95	1.00	0.85	0.85	0.85
500	1.50	1.85	1.85	1.90	2.60	2.80	2.20	1.80	2.20
700	4.50	5.60	6.00	6.60	8.00	8.10	6.00	4.40	4.00
850	10.30	11.00	11.00	11.00	11.10	11.30	12.00	10.20	8.40
1000	17.10	16.30	16.20	16.30	17.50	17.50	17.50	17.10	17.20
0									
400	0.60	0.70	0.80	0.90	1.10	1.20	0.90	1.10	0.90
500	1.60	1.90	2.00	2.30	3.00	3.20	2.80	2.20	2.10
700	5.00	6.10	7.00	8.00	8.20	8.10	7.00	6.10	5.10
850	10.70	11.20	11.40	11.70	12.10	12.00	12.20	11.30	10.50
1000	18.00	17.20	17.00	17.00	17.70	18.20	17.00	17.50	18.20

Table 1. (continued)

April		Longitude W								
		180	160	140	120	100	80	60	40	20
0										
	400	0.60	0.70	0.80	0.90	1.10	1.20	0.90	1.10	0.90
	500	1.60	1.90	2.00	2.30	3.00	3.20	2.80	2.20	2.10
	700	5.00	6.10	7.00	8.00	8.20	8.10	7.00	6.10	5.10
	850	10.70	11.20	11.40	11.70	12.10	12.00	12.20	11.30	10.50
	1000	18.00	17.20	17.00	17.00	17.70	18.20	17.00	17.90	18.20
5 S										
	400	0.65	0.70	0.85	0.95	1.10	1.10	1.00	1.10	0.85
	500	1.60	1.95	2.20	2.70	3.10	3.10	2.60	2.10	1.50
	700	5.20	6.10	6.90	8.00	8.10	7.50	7.00	6.10	4.80
	850	10.50	11.10	11.30	11.70	12.10	11.60	12.20	11.10	10.20
	1000	18.10	17.30	17.00	17.20	18.00	17.10	18.20	16.30	16.40
10 S										
	400	0.65	0.72	0.85	0.95	1.05	1.00	0.90	0.85	0.50
	500	1.55	1.65	2.10	2.40	2.70	2.70	2.00	1.60	1.30
	700	5.00	5.50	6.10	6.70	6.80	6.10	6.40	5.30	3.80
	850	10.40	10.80	11.00	11.10	11.20	10.50	12.10	9.70	9.00
	1000	18.10	17.00	16.50	16.50	17.60	15.50	16.00	0.00	15.40
15 S										
	400	0.60	0.65	0.80	0.85	0.85	0.80	0.80	0.75	0.40
	500	1.55	1.45	1.80	2.00	2.10	2.10	1.60	1.40	1.10
	700	4.70	4.80	5.20	5.30	5.30	4.80	6.00	4.30	3.10
	850	10.30	10.30	10.40	10.30	10.20	9.00	11.10	9.00	7.60
	1000	18.10	16.30	16.20	16.10	16.00	13.40	15.10	0.00	14.00
20 S										
	400	0.60	0.65	0.70	0.75	0.75	0.70	0.70	0.65	0.30
	500	1.55	1.30	1.50	1.65	1.70	1.50	1.45	0.95	0.80
	700	4.40	4.10	4.00	4.10	4.00	3.60	5.50	3.60	2.50
	850	10.10	9.50	9.60	9.40	9.00	7.30	10.00	7.70	6.50
	1000	19.00	15.60	15.30	15.30	14.70	13.50	14.30	0.00	13.00
25 S										
	400	0.60	0.55	0.55	0.60	0.55	0.45	0.60	0.45	0.25
	500	1.50	1.30	1.20	1.20	1.20	0.90	1.75	0.80	0.55
	700	4.00	3.40	3.40	3.40	3.30	2.70	4.70	3.00	1.95
	850	8.70	8.30	8.20	8.00	7.60	6.00	8.70	6.70	5.50
	1000	15.00	14.00	14.00	13.80	13.60	12.40	13.00	12.50	11.30
30 S										
	400	0.55	0.45	0.40	0.40	0.40	0.35	0.50	0.35	0.20
	500	1.15	0.90	0.80	0.80	0.70	0.50	1.10	0.70	0.40
	700	2.60	2.60	2.70	2.70	2.40	1.90	4.00	2.20	1.80
	850	7.30	6.80	6.70	6.60	6.50	4.70	7.00	5.50	4.60
	1000	11.80	12.60	12.60	12.50	12.20	10.50	12.00	10.50	9.00
35 S										
	400	0.45	0.40	0.35	0.35	0.35	0.35	0.35	0.25	0.15
	500	0.80	0.60	0.50	0.50	0.45	0.40	1.00	0.55	0.30
	700	1.90	1.80	1.90	1.90	1.80	1.50	3.10	1.80	1.50
	850	5.90	5.80	5.80	5.80	5.50	4.00	6.00	4.70	3.90
	1000	8.80	9.20	9.30	9.20	8.90	8.50	8.00	8.00	7.50

Table 1. (continued)

April	Longitude E								
	0	20	40	60	80	100	120	140	160
35 N									
400	0.25	0.30	0.30	0.35	0.40	0.50	0.55	0.55	0.45
500	0.60	0.80	1.00	1.10	1.10	1.10	1.00	1.00	0.80
700	2.10	2.10	2.10	2.20	2.30	3.80	2.80	2.30	2.00
850	4.10	4.10	4.00	5.50	0.00	0.00	4.00	4.60	4.00
1000	8.00	8.00	8.00	0.00	0.00	0.00	5.90	6.50	7.70
30 N									
400	0.20	0.25	0.35	0.50	0.70	0.80	0.95	0.70	0.45
500	0.55	0.65	0.90	1.30	1.50	2.00	1.95	1.30	0.90
700	2.00	2.00	2.00	2.80	3.50	4.50	3.00	3.20	2.40
850	2.60	3.30	4.00	6.50	0.00	0.00	6.00	6.20	6.30
1000	4.50	5.50	9.00	0.00	0.00	0.00	9.00	9.50	10.50
25 N									
400	0.20	0.20	0.40	0.65	0.70	0.90	0.90	0.50	0.45
500	0.40	0.50	1.00	1.50	2.00	2.10	2.00	1.40	1.00
700	0.90	0.90	2.00	4.00	3.60	5.80	6.00	5.70	2.80
850	1.80	1.80	4.00	6.00	5.50	9.00	8.50	7.50	7.80
1000	3.80	0.00	9.00	11.50	11.00	12.00	11.50	12.70	13.00
20 N									
400	0.40	0.35	0.50	0.80	0.95	1.05	0.60	0.40	0.50
500	0.60	0.60	1.10	1.70	2.10	2.10	1.90	1.50	1.10
700	1.00	1.00	3.00	4.60	4.20	6.00	4.50	3.80	3.20
850	2.50	2.00	4.10	7.00	6.70	10.10	9.20	8.80	8.80
1000	4.00	0.00	8.50	15.50	14.00	17.00	13.50	14.50	14.50
15 N									
400	0.60	0.55	0.60	0.95	1.10	1.10	0.50	0.50	0.60
500	1.10	1.00	1.40	2.10	2.30	2.20	1.80	1.80	1.60
700	2.00	2.00	3.10	4.70	4.20	6.00	4.00	3.70	3.80
850	4.10	4.00	6.00	9.30	7.70	10.10	9.50	9.60	9.50
1000	9.50	7.50	0.00	17.50	17.60	18.10	15.50	16.50	16.00
10 N									
400	1.00	0.80	0.80	1.10	1.15	1.10	0.65	0.80	0.85
500	2.20	1.60	1.70	2.40	2.50	2.30	1.90	1.95	2.00
700	4.50	4.80	5.50	5.70	5.20	5.90	4.70	5.30	5.80
850	8.00	7.50	6.50	11.00	10.00	10.70	10.10	10.60	10.80
1000	16.00	12.00	0.00	18.40	18.00	18.20	18.00	18.00	18.10
5 N									
400	1.20	0.85	0.95	1.20	1.25	1.20	1.00	1.10	1.10
500	3.00	2.30	2.20	2.80	2.70	2.40	2.20	2.30	2.30
700	6.30	5.80	7.20	6.60	5.80	5.80	5.90	6.20	6.20
850	12.00	11.20	11.80	12.00	10.80	11.20	10.30	11.10	12.00
1000	18.20	18.00	20.00	18.30	18.20	18.10	18.10	18.10	18.10
0									
400	1.50	1.25	1.20	1.40	1.30	1.20	1.10	1.20	1.25
500	3.00	3.00	2.90	3.10	2.80	2.50	2.30	2.50	2.60
700	6.80	8.00	8.10	7.80	6.30	6.20	6.30	6.60	6.60
850	12.20	12.20	12.20	12.30	11.50	11.70	11.00	11.30	12.10
1000	18.30	20.20	17.40	18.80	18.50	18.40	18.30	18.10	18.00

Table 1. (continued)

April	Longitude E								
	0	20	40	60	80	100	120	140	160
0									
400	1.50	1.25	1.20	1.40	1.30	1.20	1.10	1.20	1.25
500	3.00	3.00	2.90	3.10	2.80	2.50	2.30	2.50	2.60
700	6.80	8.00	8.10	7.80	6.30	6.20	6.30	6.60	6.60
850	12.20	12.20	12.20	12.30	11.50	11.70	11.00	11.30	12.10
1000	18.30	20.20	19.40	18.80	18.50	18.40	18.30	18.10	18.00
5 S									
400	1.45	1.30	1.20	1.40	1.35	1.20	1.10	1.25	1.30
500	2.70	3.20	3.20	3.30	3.00	2.40	2.30	2.70	2.80
700	6.20	8.20	8.00	8.10	7.70	6.50	6.20	6.40	6.40
850	12.10	12.30	12.10	12.20	12.10	11.60	10.40	10.60	12.10
1000	18.00	18.20	20.10	19.30	18.60	18.20	18.00	18.00	18.10
10 S									
400	1.00	1.50	1.20	1.35	1.55	1.25	1.20	1.30	1.50
500	2.10	3.10	2.60	3.10	3.00	2.20	2.20	2.40	3.00
700	5.20	8.00	6.90	7.60	7.40	5.90	5.70	6.00	6.20
850	10.60	12.10	11.50	12.00	12.00	10.70	10.10	10.10	12.00
1000	16.30	17.60	20.00	18.50	18.10	17.50	17.00	16.80	18.00
15 S									
400	0.80	1.00	0.75	1.10	1.40	1.20	1.10	1.10	1.50
500	1.50	2.50	1.85	2.20	2.30	2.00	1.90	2.00	2.80
700	4.30	7.00	6.00	6.50	6.40	5.30	5.00	5.20	6.00
850	8.60	11.10	10.50	11.00	10.80	10.00	8.30	9.30	10.50
1000	15.10	0.00	18.30	18.00	17.20	16.30	14.20	15.00	16.70
20 S									
400	0.60	0.60	0.45	0.80	1.10	1.10	1.00	0.90	1.20
500	1.30	1.80	1.50	1.70	1.80	1.80	1.60	1.80	2.20
700	3.30	5.70	5.50	5.60	5.50	4.70	4.30	4.30	5.10
850	6.70	8.40	9.50	10.20	9.70	8.90	6.50	7.00	9.00
1000	13.50	0.00	16.60	16.20	15.50	14.30	11.20	11.00	15.00
25 S									
400	0.40	0.40	0.40	0.60	0.85	0.90	0.80	0.85	0.85
500	0.95	1.50	1.30	1.50	1.60	1.55	1.40	1.60	1.70
700	2.60	4.50	4.80	4.80	4.70	4.20	3.70	3.90	4.10
850	5.00	6.30	8.70	9.00	8.60	7.80	5.60	5.80	7.70
1000	12.00	0.00	14.50	14.40	13.70	12.50	0.00	7.90	12.00
30 S									
400	0.25	0.40	0.40	0.45	0.65	0.70	0.65	0.65	0.65
500	0.60	1.00	1.10	1.20	1.35	1.35	1.20	1.25	1.40
700	2.00	3.00	4.20	4.10	3.90	3.50	3.20	3.30	3.30
850	3.80	5.50	7.90	7.80	7.20	6.50	5.20	5.00	6.60
1000	9.00	11.00	12.70	12.60	12.00	10.30	0.00	8.50	10.50
35 S									
400	0.20	0.30	0.35	0.40	0.45	0.50	0.55	0.45	0.50
500	0.45	0.75	0.85	0.95	1.10	1.10	0.95	0.90	0.95
700	1.80	2.60	3.30	3.40	3.30	2.90	2.80	2.80	2.50
850	3.80	4.30	5.30	5.50	5.40	5.00	4.20	4.20	5.30
1000	7.50	8.00	9.50	9.70	9.30	7.80	7.00	7.90	9.30

Table 1. (continued)

July	Longitude W								
	180	160	140	120	100	80	60	40	20
35 N									
400	0.55	0.40	0.35	0.40	0.60	0.80	0.70	0.60	0.45
500	1.10	0.60	0.70	1.10	1.80	1.80	1.60	1.50	1.80
700	3.30	2.00	1.70	3.40	4.50	5.50	4.50	3.70	2.70
850	7.00	6.30	4.60	4.30	10.20	10.50	8.90	7.30	6.00
1000	13.00	11.30	9.70	8.50	0.00	16.00	14.80	12.70	10.00
30 N									
400	0.60	0.40	0.40	0.50	0.80	1.00	0.70	0.60	0.50
500	1.30	0.80	0.70	1.10	1.80	2.10	1.60	1.40	1.40
700	4.00	2.50	2.10	3.30	6.00	6.00	5.00	3.90	2.70
850	8.10	7.30	5.80	5.60	10.30	11.10	9.80	8.10	6.60
1000	14.00	12.00	10.50	10.20	0.00	16.70	16.10	13.50	10.50
25 N									
400	0.70	0.45	0.45	0.60	0.90	0.95	0.80	0.70	0.60
500	1.30	0.80	0.90	1.80	1.90	1.95	1.70	1.60	1.40
700	4.10	2.80	2.80	4.00	5.90	5.90	4.90	4.00	3.00
850	9.00	8.00	7.50	8.00	11.50	11.00	10.30	9.00	7.20
1000	14.80	13.50	11.50	12.50	16.00	17.60	16.70	14.80	11.50
20 N									
400	0.70	0.55	0.50	0.80	1.25	0.90	0.80	0.70	0.70
500	1.50	0.95	1.20	2.10	3.00	1.90	1.70	1.70	1.80
700	4.20	3.40	3.30	4.60	8.00	5.80	5.30	4.20	3.70
850	10.00	9.50	9.40	10.30	11.80	11.10	10.60	10.00	8.00
1000	16.10	14.50	13.50	15.60	17.00	18.40	17.20	16.00	13.70
15 N									
400	0.80	0.60	0.65	0.95	1.50	0.95	0.90	0.70	0.90
500	1.70	1.20	1.60	2.30	3.10	1.90	1.90	1.70	2.10
700	4.30	3.70	3.90	5.70	8.10	5.90	5.60	4.60	5.20
850	10.30	10.40	10.80	11.80	12.10	11.70	10.70	10.20	10.00
1000	16.50	15.50	15.50	18.00	19.50	19.00	17.70	16.20	15.80
10 N									
400	0.90	0.70	0.90	1.20	1.55	1.05	0.95	0.75	1.00
500	2.00	1.70	2.05	2.40	3.05	3.00	2.00	1.70	2.05
700	4.50	4.50	5.30	6.90	8.50	6.30	5.90	5.00	6.00
850	10.50	11.30	11.70	12.10	12.40	12.10	11.20	10.60	10.20
1000	17.20	16.50	17.60	18.80	20.00	18.80	17.50	16.30	17.70
5 N									
400	1.00	0.70	1.10	1.20	1.30	1.20	1.00	0.70	0.70
500	2.00	1.95	2.30	2.60	2.90	3.00	2.10	1.50	1.70
700	5.10	5.60	6.20	7.70	8.10	7.20	6.00	4.70	5.60
850	10.40	11.50	12.20	12.20	12.10	12.00	11.40	10.60	10.20
1000	18.00	17.00	18.00	18.00	18.00	18.00	17.10	16.50	16.90
0									
400	1.00	0.80	0.95	0.95	0.95	0.90	0.85	0.60	0.55
500	2.00	1.90	2.00	2.00	2.20	2.20	1.90	1.30	1.20
700	5.00	5.80	6.70	7.50	7.60	6.60	5.80	4.40	4.40
850	10.60	10.80	11.90	11.70	11.50	10.80	11.10	9.60	9.40
1000	18.10	17.00	17.40	16.20	15.50	13.50	16.60	16.20	15.20

Table 1. (continued)

July	Longitude W								
	180	160	140	120	100	80	60	40	20
0									
400	1.00	0.80	0.95	0.95	0.95	0.90	0.85	0.60	0.55
500	2.00	1.90	2.00	2.00	2.20	2.20	1.90	1.30	1.20
700	5.00	5.80	6.70	7.50	7.60	6.60	5.80	4.40	4.40
850	10.60	10.80	11.90	11.70	11.50	10.80	11.10	9.60	9.40
1000	18.10	17.00	17.40	16.20	15.50	13.50	16.60	16.20	15.20
5 S									
400	1.00	0.70	0.85	0.80	0.60	0.50	0.70	0.45	0.40
500	2.00	1.60	1.80	1.80	1.90	1.90	1.20	1.10	0.95
700	4.70	5.30	6.20	6.70	6.70	5.50	5.00	4.10	3.30
850	10.30	9.80	10.20	10.50	10.30	8.70	9.50	8.90	8.60
1000	18.00	16.80	16.60	15.50	14.50	16.00	15.50	15.00	13.70
10 S									
400	0.60	0.65	0.70	0.65	0.60	0.55	0.60	0.40	0.35
500	1.50	1.20	1.30	1.30	1.30	1.25	1.00	1.10	0.80
700	4.30	4.60	5.60	6.00	5.80	4.00	3.60	3.80	2.20
850	10.10	9.20	9.50	9.50	9.30	6.00	8.70	8.00	7.80
1000	18.00	16.30	16.00	14.50	14.20	11.00	14.00	0.00	12.00
15 S									
400	0.50	0.50	0.60	0.50	0.45	0.40	0.40	0.30	0.30
500	1.20	1.00	1.30	1.30	1.25	1.20	0.90	1.00	0.70
700	4.00	3.90	4.70	5.00	4.70	2.20	3.30	2.90	1.95
850	9.20	8.70	8.80	8.70	8.20	6.60	6.50	7.20	7.30
1000	16.30	15.10	14.50	13.50	13.40	10.60	12.00	0.00	11.00
20 S									
400	0.40	0.45	0.45	0.40	0.35	0.30	0.40	0.25	0.20
500	1.00	0.90	1.05	1.05	1.05	0.95	0.90	0.90	0.60
700	3.30	3.30	4.00	4.00	4.00	2.40	3.10	2.20	0.90
850	8.40	8.20	8.30	8.00	7.30	4.80	6.00	6.70	6.70
1000	14.30	13.80	13.50	12.70	12.50	10.30	12.00	0.00	9.60
25 S									
400	0.40	0.40	0.35	0.30	0.25	0.20	0.30	0.20	0.15
500	0.75	0.70	0.80	0.80	0.80	0.75	0.80	0.80	0.50
700	2.50	2.60	2.80	3.00	3.00	1.90	3.00	1.90	1.50
850	6.60	6.70	6.80	6.70	6.40	4.40	5.00	5.90	6.10
1000	11.50	11.50	11.50	11.50	11.00	9.50	10.00	10.10	8.60
30 S									
400	0.30	0.30	0.25	0.20	0.15	0.10	0.30	0.30	0.15
500	0.50	0.55	0.60	0.60	0.60	0.65	0.70	0.65	0.40
700	1.80	1.80	1.90	2.00	2.00	1.70	3.00	1.80	1.30
850	5.10	5.30	5.50	5.30	5.30	3.80	4.50	5.10	5.20
1000	9.30	9.00	9.00	9.00	9.50	8.00	8.40	8.80	7.50
35 S									
400	0.20	0.20	0.15	0.15	0.10	0.05	0.25	0.15	0.10
500	0.35	0.35	0.35	0.35	0.35	0.40	0.60	0.55	0.40
700	1.20	1.30	1.30	1.40	1.40	1.20	2.20	1.60	1.20
850	3.80	4.00	4.10	4.20	4.10	3.20	4.00	4.30	4.00
1000	5.30	5.30	5.30	5.30	5.10	4.00	7.50	7.70	6.70

Table 1. (continued)

July — Longitude E

	0	20	40	60	80	100	120	140	160
35 N									
400	0.40	0.45	0.50	1.90	1.80	2.50	1.80	1.55	1.10
500	1.00	1.00	2.00	2.50	3.50	4.00	3.30	2.60	1.80
700	2.30	2.70	4.50	7.00	6.00	7.00	7.80	6.30	4.30
850	6.00	6.10	6.20	8.00	0.00	0.00	12.60	10.70	8.60
1000	8.50	15.00	12.50	0.00	0.00	0.00	18.20	17.90	15.80
30 N									
400	0.40	0.40	0.45	1.40	2.40	2.80	1.70	1.50	1.05
500	1.20	1.20	2.00	3.00	4.10	5.00	3.40	2.60	1.90
700	1.90	2.50	2.00	8.40	10.00	10.00	7.50	6.30	5.00
850	2.00	5.20	4.00	9.50	0.00	0.00	13.50	11.40	9.50
1000	8.20	13.50	11.00	0.00	0.00	0.00	19.20	18.20	16.50
25 N									
400	0.40	0.40	0.50	1.45	2.70	2.60	1.60	1.40	1.05
500	1.00	1.00	1.50	3.20	4.90	5.00	3.20	2.60	2.00
700	1.80	1.80	1.80	6.30	10.00	9.70	7.40	6.50	5.50
850	2.00	5.30	4.00	8.50	14.30	14.20	13.30	11.80	10.50
1000	7.50	0.00	20.00	19.00	20.00	19.50	19.80	18.00	17.50
20 N									
400	0.45	0.50	1.10	1.45	2.60	2.40	1.50	1.40	1.10
500	1.70	1.70	2.00	2.80	4.30	4.40	2.90	2.60	2.10
700	3.00	2.00	3.00	6.00	9.20	9.80	7.00	6.50	6.00
850	6.60	3.70	12.00	9.00	14.00	14.10	13.60	12.50	11.70
1000	11.70	0.00	16.00	19.50	19.60	19.80	19.90	18.80	17.50
15 N									
400	0.75	1.10	1.60	1.45	2.00	1.95	1.45	1.40	1.10
500	2.00	2.00	3.10	2.80	3.80	4.00	2.90	2.80	2.50
700	4.50	4.00	7.00	6.20	8.30	8.10	7.00	6.80	6.60
850	9.50	7.00	12.10	12.30	12.20	12.20	12.00	12.70	12.20
1000	12.00	13.00	0.00	19.50	18.00	19.40	19.50	18.80	18.00
10 N									
400	1.20	1.30	1.80	1.40	1.80	1.60	1.45	1.50	1.20
500	2.30	2.70	4.00	2.80	3.50	3.50	3.10	3.00	2.80
700	6.10	5.30	8.30	7.40	7.50	7.80	7.30	7.10	7.10
850	10.10	10.20	12.10	12.70	11.90	11.70	11.50	12.30	12.20
1000	18.20	16.20	0.00	19.30	18.00	18.90	18.80	18.50	18.20
5 N									
400	1.05	1.10	1.50	1.40	1.55	1.40	1.40	1.55	1.35
500	2.00	2.20	3.60	2.80	3.10	3.20	3.20	3.20	3.05
700	6.30	6.00	8.30	7.00	7.00	7.10	7.20	7.20	7.10
850	10.00	10.90	12.00	12.20	11.60	11.40	11.20	11.80	11.80
1000	16.00	16.80	16.00	18.70	18.20	18.30	18.20	18.20	18.50
0									
400	0.80	0.90	1.00	1.20	1.40	1.30	1.20	1.40	1.35
500	1.60	1.80	2.50	2.50	2.80	2.80	2.80	3.00	3.00
700	5.40	6.10	8.00	6.70	6.70	6.60	6.70	7.20	7.00
850	9.50	11.00	11.00	11.60	11.20	10.90	10.60	10.90	11.30
1000	14.50	16.10	16.00	18.10	18.00	18.00	17.40	17.40	18.20

Table 1. (continued)

July	Longitude E								
	0	20	40	60	80	100	120	140	160
0									
400	0.80	0.90	1.00	1.20	1.40	1.30	1.20	1.40	1.35
500	1.60	1.80	2.50	2.50	2.80	2.80	2.80	3.00	3.00
700	5.40	6.10	8.00	6.70	6.70	6.60	6.70	7.20	7.00
850	9.50	11.00	11.00	11.60	11.20	10.90	10.60	10.90	11.30
1000	14.50	16.10	16.00	18.10	18.00	18.00	17.40	17.40	18.20
5 S									
400	0.55	0.60	0.75	1.18	1.25	1.20	1.20	1.20	1.20
500	1.20	1.40	1.70	2.30	2.50	2.60	2.50	2.60	2.60
700	4.30	5.40	6.00	6.30	6.40	6.00	5.70	7.00	6.40
850	8.90	10.00	9.80	10.50	10.60	10.60	10.30	10.30	10.80
1000	13.30	12.00	17.00	17.10	17.20	17.00	16.70	16.20	17.80
10 S									
400	0.45	0.50	0.50	0.90	1.10	1.10	1.05	1.00	1.10
500	0.90	1.00	1.20	2.00	2.20	2.20	2.10	2.00	2.20
700	2.90	4.30	4.90	6.00	6.20	5.40	5.00	5.20	4.00
850	8.20	8.20	8.90	9.60	10.20	10.20	9.00	8.20	10.40
1000	11.50	11.00	15.30	15.50	16.30	16.00	15.00	14.20	16.70
15 S									
400	0.35	0.25	0.35	0.70	0.95	0.95	0.90	0.90	0.95
500	0.60	0.60	0.50	1.45	1.95	1.95	1.80	1.80	1.90
700	1.95	3.50	3.80	4.80	5.40	4.80	4.20	3.70	4.00
850	7.20	6.60	7.40	8.70	9.30	8.80	6.90	6.80	9.80
1000	10.50	0.00	13.50	13.50	13.50	12.70	10.20	9.50	14.00
20 S									
400	0.25	0.20	0.30	0.50	0.75	0.80	0.80	0.80	0.80
500	0.45	0.55	0.50	0.95	1.40	1.55	1.55	1.60	1.65
700	0.90	2.70	3.40	3.90	4.60	4.50	3.60	3.50	3.50
850	6.50	5.10	7.20	8.10	8.00	7.30	5.10	5.00	8.00
1000	9.50	0.00	12.00	11.20	11.20	10.50	8.00	8.00	11.00
25 S									
400	0.15	0.15	0.30	0.40	0.55	0.60	0.65	0.65	0.65
500	0.45	0.50	0.60	0.80	0.95	1.10	1.30	1.25	1.30
700	1.50	2.00	2.90	3.30	3.60	3.70	3.10	2.80	2.90
850	5.40	3.30	6.40	6.60	6.40	5.70	4.00	3.90	5.90
1000	8.00	0.00	10.00	9.50	9.50	9.00	0.00	5.80	8.00
30 S									
400	0.15	0.20	0.30	0.35	0.40	0.50	0.55	0.50	0.50
500	0.35	0.40	0.60	0.65	0.75	0.85	1.00	1.00	1.00
700	1.30	1.80	2.30	2.60	2.70	2.70	2.30	2.10	2.30
850	4.40	2.00	5.20	5.20	5.20	5.10	3.80	3.70	4.80
1000	7.20	7.30	8.00	7.80	7.90	7.80	0.00	5.80	7.50
35 S									
400	0.10	0.15	0.20	0.30	0.40	0.40	0.40	0.40	0.35
500	0.30	0.35	0.45	0.55	0.60	0.65	0.75	0.75	0.75
700	1.20	1.50	1.90	2.10	2.20	2.00	1.90	1.90	2.00
850	3.70	2.00	4.10	4.20	4.20	4.30	3.70	3.40	4.10
1000	6.30	6.60	6.80	7.00	7.00	7.00	6.20	6.00	6.60

Table 1. (continued)

October	Longitude W								
	180	160	140	120	100	80	60	40	20
35 N									
400	0.40	0.30	0.30	0.30	0.40	0.40	0.60	0.60	0.40
500	0.90	0.80	0.80	0.80	0.90	0.95	1.20	1.20	1.10
700	2.70	1.80	1.80	2.30	3.10	2.90	3.10	3.50	2.08
850	6.60	6.20	5.50	3.80	4.80	5.90	7.50	8.10	7.00
1000	11.00	11.00	9.60	8.00	0.00	8.00	8.00	12.50	10.50
30 N									
400	0.50	0.40	0.40	0.45	0.40	0.60	0.70	0.60	0.40
500	1.10	0.90	0.90	0.95	2.00	1.40	1.40	1.25	0.80
700	3.00	2.40	2.40	2.80	3.90	3.50	4.00	4.20	3.00
850	7.60	7.20	6.00	4.90	7.00	7.80	8.50	8.80	8.00
1000	13.00	12.70	11.90	9.60	0.00	12.20	13.30	12.50	11.20
25 N									
400	0.60	0.50	0.50	0.60	0.75	0.80	0.80	0.60	0.35
500	1.20	0.95	0.95	1.10	1.60	1.60	1.70	1.20	0.90
700	3.40	2.80	2.80	3.60	5.20	4.50	4.50	4.30	3.70
850	8.60	8.20	7.30	7.20	8.50	9.30	9.20	9.30	8.20
1000	15.00	13.70	12.90	12.00	12.00	15.50	14.50	13.20	12.10
20 N									
400	0.70	0.60	0.80	0.80	1.00	1.00	0.90	0.60	0.35
500	1.50	1.10	1.10	1.60	2.20	2.30	1.70	1.20	0.90
700	3.80	3.40	3.60	5.20	7.00	6.20	5.20	4.80	3.80
850	9.80	9.50	9.00	9.50	11.00	11.00	9.80	9.80	8.20
1000	16.10	15.00	13.80	14.00	17.00	17.00	15.80	14.50	13.20
15 N									
400	0.85	0.65	0.70	0.95	1.20	1.20	0.90	0.60	0.40
500	1.70	1.30	1.45	2.00	2.70	2.60	1.80	1.20	0.95
700	4.00	4.10	4.40	6.80	8.00	6.60	5.50	5.00	3.80
850	10.10	10.20	10.30	10.90	11.70	12.10	10.30	10.20	8.00
1000	16.10	15.80	15.00	16.00	18.20	18.20	17.00	15.60	16.00
10 N									
400	1.00	0.70	0.90	1.15	1.50	1.45	1.00	0.60	0.55
500	1.90	1.40	1.75	2.70	3.10	3.00	2.00	1.30	1.20
700	4.40	4.80	5.50	7.80	8.20	7.00	6.10	5.30	4.30
850	10.30	10.50	11.00	11.60	12.10	12.10	11.00	10.50	9.40
1000	16.20	16.20	16.00	17.00	18.10	18.20	18.10	16.50	16.20
5 N									
400	1.00	0.75	0.95	1.35	1.50	1.45	1.10	0.70	0.80
500	2.00	1.40	2.00	2.90	3.10	3.00	2.25	1.50	1.50
700	4.20	4.70	6.00	8.10	8.20	7.90	6.70	5.30	5.20
850	10.10	10.40	11.30	12.10	12.20	12.00	11.30	10.30	10.40
1000	16.10	16.20	16.20	17.00	17.30	18.00	17.00	16.70	16.20
0									
400	1.10	0.70	1.05	1.30	1.30	1.10	1.00	0.60	0.65
500	2.10	1.35	2.15	2.70	2.90	2.80	2.30	1.30	1.10
700	4.10	4.20	6.20	8.10	8.10	7.50	6.70	4.10	4.80
850	10.10	10.20	11.30	12.00	11.90	11.10	11.20	10.05	10.50
1000	16.00	16.10	16.20	15.80	15.70	16.20	16.00	16.20	15.00

Table 1. (continued)

October	Longitude W								
	180	160	140	120	100	80	60	40	20
0									
400	1.10	0.70	1.05	1.30	1.30	1.10	1.00	0.60	0.65
500	2.10	1.35	2.15	2.70	2.90	2.80	2.30	1.30	1.10
700	4.10	4.20	6.20	8.10	8.10	7.50	6.70	4.10	4.80
850	10.10	10.20	11.30	12.00	11.90	11.10	11.20	10.05	10.50
1000	16.00	16.10	16.20	15.80	15.70	16.20	16.00	16.20	15.00
5 S									
400	1.00	0.70	1.10	1.30	1.10	0.95	0.90	0.50	0.50
500	2.00	1.40	2.20	2.60	2.70	2.60	2.10	1.00	0.90
700	4.05	4.00	6.10	7.30	7.70	6.60	6.50	3.50	3.70
850	10.05	9.90	11.00	11.40	11.00	10.00	11.10	9.60	9.00
1000	15.30	15.50	15.60	15.00	14.70	13.70	14.00	15.30	13.70
10 S									
400	0.95	0.65	1.05	1.05	0.95	0.80	0.75	0.45	0.40
500	1.80	1.35	2.20	2.40	2.50	2.30	1.90	0.90	0.80
700	4.10	3.80	5.80	6.90	6.70	5.20	6.30	3.40	2.70
850	10.10	9.30	10.80	11.00	10.70	8.00	10.00	9.50	7.70
1000	14.50	14.60	14.70	14.30	14.10	11.60	13.00	0.00	12.50
15 S									
400	0.70	0.60	1.00	0.90	0.80	0.65	0.65	0.50	0.35
500	1.40	1.25	2.05	2.20	2.20	2.05	1.60	0.90	0.70
700	4.00	3.70	5.30	6.20	6.00	3.80	6.00	3.30	1.90
850	10.10	8.60	10.40	10.60	10.20	7.30	8.00	9.30	7.00
1000	13.50	13.70	13.70	13.50	13.30	10.80	11.00	0.00	11.60
20 S									
400	0.60	0.60	0.80	0.80	0.70	0.60	0.55	0.50	0.30
500	1.20	1.30	1.80	2.00	2.00	1.60	1.40	0.90	0.60
700	3.30	3.50	4.70	5.20	4.70	3.90	4.00	3.00	1.50
850	9.80	8.00	10.10	10.20	9.50	6.90	7.00	8.60	6.40
1000	12.80	12.90	13.00	12.80	12.50	10.50	12.70	0.00	11.00
25 S									
400	0.45	0.45	0.65	0.60	0.55	0.40	0.45	0.40	0.20
500	1.00	1.10	1.40	1.60	1.60	1.00	1.20	0.65	0.50
700	2.60	2.50	3.80	4.00	3.30	2.00	3.90	2.00	1.10
850	7.50	7.30	8.70	9.00	8.60	6.50	7.80	7.30	5.30
1000	11.70	11.70	11.70	11.90	11.20	9.50	9.00	9.50	9.60
30 S									
400	0.30	0.35	0.45	0.45	0.40	0.30	0.35	0.30	0.15
500	0.80	0.85	1.00	1.10	1.00	0.70	1.20	0.50	0.40
700	1.80	2.00	2.60	2.70	2.40	1.50	3.10	1.70	0.80
850	5.80	6.40	7.20	7.50	7.20	5.80	6.50	6.00	4.40
1000	10.20	10.20	10.20	10.40	9.70	8.40	10.00	10.00	9.00
35 S									
400	0.20	0.25	0.35	0.35	0.30	0.25	0.30	0.25	0.10
500	0.60	0.60	0.70	0.75	0.70	0.50	1.10	0.45	0.30
700	1.50	1.50	1.70	1.80	1.60	1.00	2.70	1.20	0.60
850	5.00	5.30	5.90	6.20	6.20	4.60	5.30	4.50	3.50
1000	8.80	8.70	8.70	8.70	8.30	7.90	8.10	8.70	7.80

Table 1. (continued)

October	Longitude E								
	0	20	40	60	80	100	120	140	160
35 N									
400	0.50	0.40	0.30	0.60	0.50	0.95	0.80	0.75	0.65
500	1.00	1.00	0.70	1.20	1.00	2.00	1.60	1.30	1.20
700	2.10	2.70	2.50	4.00	2.80	4.00	2.90	3.90	3.40
850	4.50	6.00	4.50	5.08	0.00	0.00	4.30	7.00	7.10
1000	8.00	15.00	12.50	0.00	0.00	0.00	9.00	17.00	15.90
30 N									
400	0.30	0.25	0.25	0.60	0.80	1.25	0.95	0.80	0.70
500	0.90	0.90	0.50	1.40	1.70	2.80	1.90	1.45	1.45
700	4.00	2.20	2.00	4.30	3.90	6.00	4.00	4.50	4.00
850	1.80	3.70	4.00	4.50	0.00	0.00	8.60	10.20	8.70
1000	6.50	10.00	9.00	0.00	0.00	0.00	4.00	13.30	14.30
25 N									
400	0.20	0.20	0.25	0.50	1.10	1.50	1.05	0.80	0.80
500	0.90	0.90	0.70	1.30	2.50	3.00	2.10	1.70	1.70
700	0.60	1.70	2.00	3.80	5.30	8.00	4.80	5.00	4.70
850	2.00	1.80	3.90	5.50	9.50	11.00	8.50	10.40	10.00
1000	8.00	0.00	10.00	16.00	16.00	11.00	10.50	16.30	16.20
20 N									
400	0.20	0.20	0.30	0.50	1.20	1.50	1.00	0.90	0.90
500	0.90	0.90	1.05	1.20	2.60	3.10	2.10	1.95	1.95
700	1.60	1.90	3.10	4.10	6.80	8.00	5.50	5.60	5.50
850	3.50	2.00	5.00	6.00	11.00	12.00	10.00	10.80	11.10
1000	10.30	0.00	12.00	16.50	17.00	15.00	14.30	17.20	18.00
15 N									
400	0.35	0.30	0.50	0.80	1.40	1.40	1.00	1.00	1.00
500	0.95	0.95	1.30	1.80	2.70	3.00	2.10	2.40	2.35
700	2.60	2.80	4.80	6.00	7.30	7.80	6.00	6.20	6.20
850	5.50	3.90	8.00	7.30	11.60	12.00	10.80	11.00	11.40
1000	14.20	9.50	0.00	17.00	17.80	17.80	16.10	18.00	18.20
10 N									
400	0.80	0.50	0.90	1.05	1.45	1.40	1.10	1.30	1.25
500	1.50	1.60	1.70	2.10	2.80	2.95	2.50	2.70	2.75
700	4.20	4.20	6.10	6.80	7.70	7.70	6.60	7.00	6.90
850	9.20	9.00	8.00	8.80	11.70	11.90	11.20	11.10	11.10
1000	15.00	16.00	0.00	16.00	18.00	18.00	16.60	18.10	18.10
5 N									
400	1.10	0.90	0.95	1.10	1.50	1.50	1.40	1.45	1.50
500	2.20	2.20	2.00	2.20	2.80	3.00	2.40	3.00	3.20
700	6.20	6.00	7.20	7.10	7.00	7.40	6.70	7.10	7.10
850	12.00	10.30	10.00	10.30	11.60	11.50	11.20	11.20	11.20
1000	16.10	16.10	17.00	18.20	18.10	18.20	16.80	18.00	17.80
0									
400	1.20	1.50	0.90	1.15	1.60	1.50	1.20	1.40	1.55
500	2.30	3.00	2.30	2.30	3.00	3.00	2.60	3.00	3.20
700	6.90	8.00	7.90	7.30	6.70	7.00	6.40	7.00	7.10
850	12.20	12.00	11.10	11.00	11.40	11.00	10.80	11.05	11.10
1000	15.50	16.20	17.00	18.10	18.10	18.00	17.00	17.40	17.30

Table 1. (continued)

October	Longitude E								
	0	20	40	60	80	100	120	140	160
0									
400	1.20	1.50	0.90	1.15	1.60	1.50	1.20	1.40	1.55
500	2.30	3.00	2.30	2.30	3.00	3.00	2.60	3.00	3.20
700	6.90	8.00	7.90	7.30	6.70	7.00	6.40	7.00	7.10
850	12.20	12.00	11.10	11.00	11.40	11.00	10.80	11.05	11.10
1000	15.50	16.20	17.00	18.10	18.10	18.00	17.00	17.40	17.30
5 S									
400	1.00	1.60	0.80	1.10	1.55	1.30	1.05	1.20	1.50
500	2.00	3.10	2.00	2.40	3.05	2.80	2.50	2.70	3.10
700	6.60	8.20	7.00	7.05	6.20	6.00	6.00	6.50	7.00
850	12.00	12.10	11.00	11.10	11.20	10.40	9.80	10.40	11.05
1000	13.90	15.70	18.10	18.00	17.80	17.30	16.60	17.00	16.80
10 S									
400	0.80	1.40	0.80	1.00	1.45	1.00	0.85	0.95	1.20
500	1.50	2.90	1.75	2.25	3.00	2.30	1.95	2.20	2.60
700	5.20	8.00	5.70	6.20	5.30	4.70	5.30	5.50	6.20
850	9.20	12.00	10.80	11.10	10.70	9.50	8.70	8.80	10.90
1000	12.10	14.00	17.20	16.60	16.00	15.50	16.20	16.40	16.40
15 S									
400	0.60	0.95	0.65	0.85	1.15	0.85	0.80	0.80	0.95
500	1.00	2.20	1.50	1.90	2.30	1.85	1.80	1.80	1.95
700	3.50	5.70	5.20	5.00	4.00	3.50	4.50	4.70	4.80
850	6.60	9.00	10.10	10.10	9.30	8.30	7.20	7.30	9.00
1000	11.20	0.00	15.50	15.00	14.30	13.50	12.00	14.50	15.30
20 S									
400	0.40	0.70	0.60	0.70	0.90	0.80	0.65	0.65	0.80
500	0.80	1.80	1.20	1.50	1.75	1.55	1.60	1.55	1.50
700	2.50	4.00	4.70	3.90	3.30	3.20	3.70	4.00	3.80
850	5.20	6.00	6.20	8.70	8.50	7.20	5.50	6.00	7.50
1000	10.50	0.00	13.50	13.30	12.70	11.40	8.20	10.00	13.40
25 S									
400	0.25	0.45	0.45	0.50	0.65	0.60	0.55	0.50	0.65
500	0.70	1.45	1.00	1.00	1.35	1.25	1.25	1.35	1.30
700	1.60	3.20	4.00	3.15	2.75	2.70	2.90	3.30	3.40
850	4.00	4.80	8.00	7.50	7.30	6.10	4.10	5.00	6.00
1000	9.00	0.00	12.30	11.10	10.90	9.60	0.00	7.80	11.00
30 S									
400	0.20	0.30	0.40	0.40	0.45	0.45	0.40	0.40	0.55
500	0.50	1.00	0.80	0.75	0.90	0.90	0.90	1.10	1.10
700	0.90	2.10	3.00	2.40	2.10	2.10	2.30	2.70	2.90
850	3.50	4.40	6.00	6.60	6.30	5.30	3.80	4.00	5.20
1000	8.00	8.00	7.50	9.30	9.00	7.90	0.00	7.20	8.00
3[illegible]									
400	0.10	0.20	0.30	0.35	0.40	0.40	0.40	0.40	0.45
500	0.40	0.75	0.60	0.55	0.68	0.70	0.80	0.90	0.90
700	0.70	1.00	1.90	1.80	1.60	1.60	1.70	2.10	2.10
850	3.00	3.80	5.20	5.50	5.20	4.30	3.80	3.90	4.30
1000	7.60	7.60	7.80	7.80	7.80	7.60	7.50	7.50	7.60

Table 1. (continued)

4. Specific humidity model

Monthly **mean** values of specific humidity q have been taken from the maps of Newell et al. (1972, Plates 5.1 to 5.5) for the months of January, April, July and October at 1000, 850, 700, 500 and 400 mb. The maps cover 40 S to 40 N and were read at intervals of 5^{o} latitude from 35 S to 35 N at every 20^{o} longitude. Tabulations of the model are given in Table 1. For higher latitudes the ratio of q to its value at 35^{o} latitude and the same longitude has been taken from Table 2, where values are based on the corresponding ratios for surface values adopted by Siebert (1961, Fig. 9).

Above 400 mb, specific humidity data are very sparse, but it is well established that q shows relatively little variation with height in the lower stratosphere (Mastenbrook, 1971; Harries, 1976; Hyson, 1978). At 100 mb a value of q = 2.5×10^{-6} has been adopted for all latitudes, longitudes and seasons; and values of q between p_1 = 100 mb and p_2 = 400 mb have been interpolated by a cubic in pressure which fits the data for $q^{\frac{1}{N}}$ tangentially at these end points. The value of q at pressure p is then

$$q = Q^{N} \tag{4.1}$$

where

Table 2. Values adopted for the ratio of specific humidity at latitudes greater than 35° to the value at 35° latitude and the same longitude. N - in the N hemisphere; S - in the S hemisphere

Lat	Jan N/ Jul S	Jul N/ Jan S	Apr/Oct N or S
35	1 00	1.00	1.00
40	0.84	0.85	0.79
45	0.65	0.71	0.65
50	0.49	0.62	0.51
55	0.39	0.50	0.41
60	0.29	0.41	0.33
65	0.19	0.35	0.29
70	0.13	0.27	0.21
75	0.10	0.23	0.17
80	0.07	0.17	0.14
85	0.03	0.15	0.09
90	0.00	0.08	0.08

$$Q = \frac{(p-p_1)^2}{(p_2-p_1)^2}\left[(p-p_2)\left(\frac{dQ}{dp}\right)_{p=p_2} + \left(1 - 2\,\frac{p-p_2}{p_2-p_1}\right)Q_2\right] + \frac{(p-p_2)^2}{(p_1-p_2)^2}\left(1 - 2\,\frac{p-p_1}{p_1-p_2}\right)Q_1 \qquad (4.2)$$

$$Q_i = q_i^{\frac{1}{N}} \qquad (i = 1, 2) \qquad (4.3)$$

N is chosen so that $q^{\frac{1}{N}}$ is approximately proportional to p over much of the pressure range: for the upper troposphere N = 4 is appropriate (Siebert, 1961, p. 170) and this value has been taken. The gradient $(dQ/dp)_{p=p_2}$ is obtained by fitting a quadratic in p to values of Q at p_2 = 400 mb, p_3 = 500 mb and p_4 = 700 mb; this gives

$$\left(\frac{dQ}{dp}\right)_{p=p_2} = \frac{Q_3 - Q_2}{p_3 - p_2} - \frac{Q_4 - Q_3}{p_4 - p_3} + \frac{Q_4 - Q_2}{p_4 - p_2} \qquad (4.4)$$

To illustrate the nature of the profiles obtained for q by the above method, Fig. 1 has been drawn to show the January and July profiles at latitudes 0, 30 and 60 N for longitude 0°. The profiles are generally similar to those presented by London and Park (1973, Fig. 3). All graphs in this paper are plotted with a vertical scale $x = \ln(p_o/p)$ and approximate heights are shown corresponding to a scale

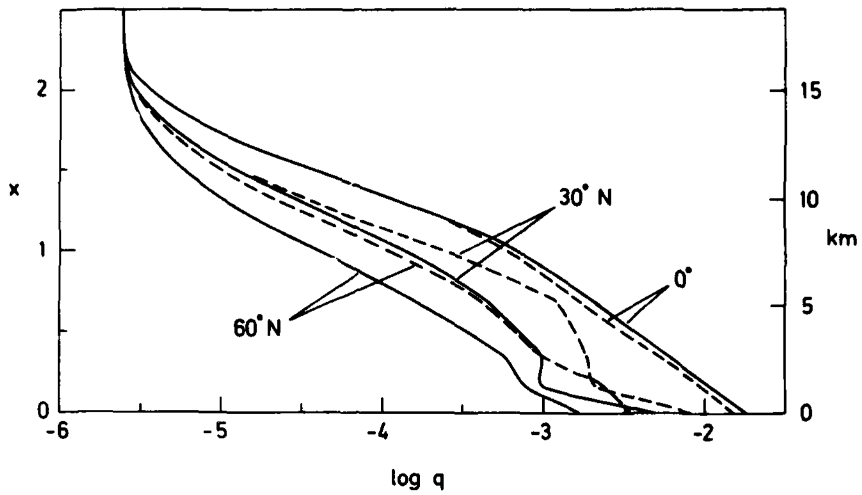

Fig. 1 Profiles of log specific humidity q (g/g) versus x (= $\ln(p_o/p)$) for longitude 0^o.

Key: —— January; - - - - July.

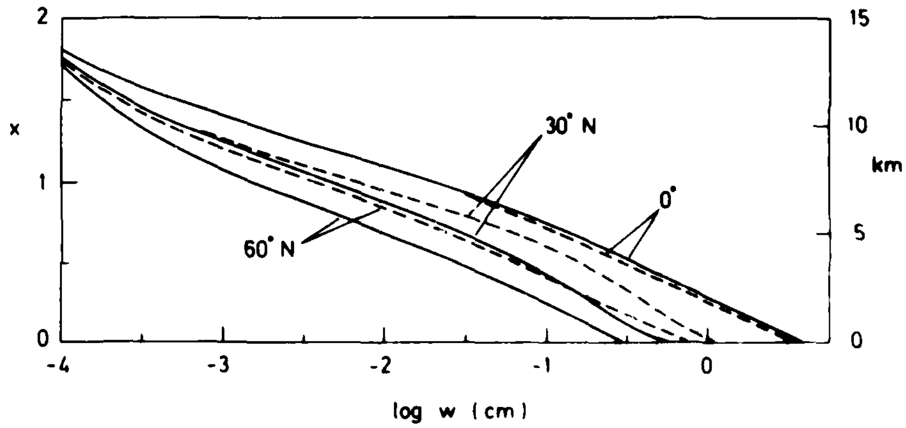

Fig. 2 Profiles of log effective water vapour amount w (cm) above a given pressure p for longitude 0^o.

Key: —— January; - - - - July. $x = \ln(p_o/p)$.

height of 7.5 km.

At low latitudes the variation of q in longitude is characterized by three regions of maxima located over Africa, America/Eastern Pacific and S.E. Asia. Although the difference between maximum and minimum values around a circle of latitude is relatively small near the surface, the maximum/minimum ratio sometimes exceeds 2 above 700 mb. The three regions of maxima shift northwards or southwards into the summer hemisphere by about 10° of latitude, the largest excursion being in July at Asian monsoon longitudes (Newell et al., 1972). In the lower atmosphere, specific humidity may depend on time of day due to daily variations in vertical turbulent transfer and evaporation rate: such variations which are usually confined to the lowest 2 or 3 km of the atmosphere will not be taken into account.

Fig. 2 shows the effective water vapour amount w above a given height corresponding to the curves for q in Fig. 1. Below 5 to 8 km according to latitude, $w > 10^{-2}$ cm and the absorption formula (2.3) holds to better than 1 per cent as by (2.4) $y > 10^{-2}$ cm. The formula will nevertheless be applied for all values of y that arise although its accuracy for $y < 10^{-2}$ cm has not been stated. For $y < 0.2 \times 10^{-2}$ cm, the linear approximation to (2.3) holds and accuracies would be expected to be of the same order as at $y = 0.2 \times 10^{-2}$ cm.

5. Absorption, scattering, albedo and cloud amount data

Sets of water vapour absorption coefficients have been presented by several authors: Somerville et al., (1974) approximated (2.3) by a series of 6 exponential terms in (3.2) and Lacis and Hansen (1974) by a series of 8 terms. Tiedtke and Geleyn (1975) used 7 terms to represent the transmissivity values of Manabe and Möller (1961). Kerschens et al., (1976) fitted exponential series to each of eight absorption bands using the spectral data of Moskalenko and Golubitskiy (1968) and obtained a total of 36 terms. Welch et al., (1976) treated composite spectral intervals introducing 14 terms in all. The data of Somerville et al., (1974) which are adopted for the main calculations in this paper are given in Table 3.

Table 3. Water vapour absorption coefficients k_i and associated probabilities a_i from Somerville et al., (1974)

a_i	0.647	0.107	0.104	0.073	0.044	0.025
k_i cm^{-1}	7×10^{-5}	0.005	0.041	0.416	4.75	72.5

For cloud scattering data, we follow Lacis and Hansen (1974) and take cloud optical depth $\tau_c = 8$ for a typical middle level cloud having a water vapour content $w_c = 0.20$ cm. Modified cloud optical depth χ_c^*, which is the same as $(5/3)\tau_c$, is related to w_c by the first term on the right-hand side of (3.5), i.e.

$$\chi_c^* = \frac{5}{3}\sigma w_c$$

Hence for a typical middle level cloud $\sigma = 40$ cm^{-1}; and this value is adopted for the main calculations below.

Droplet absorption in a typical middle level cloud has been stated by Lacis and Hansen (1974) to be equivalent to the relatively small addition of 0.08 cm of water vapour with no droplet absorption. As water vapour is the predominant source of absorption, a rather rough allowance for droplet absorption is made by increasing the water vapour absorption coefficients by 40 per cent.

For the main calculations we take $f = 0.925$ which corresponds with the choice of $g = 0.85$ in previous analyses (Lacis and Hansen, 1974) to which it is related by $1 - f = \frac{1}{2}(1 - g)$.

Surface albedoes for each 10° latitude x 10° longitude area are assigned one of the values 0.07, 0.14, 0.21 or 0.75 according to whether the area is categorized as all sea, all

```
Lat   180 W     90        0        90       180 E
        :        :        :        :        :
  90    #####################################
  80    #####################################
  70    #####################################
  60      +++XXXX+++ +     ++XXXXXXXXXXXX+++
  50          XXXXXX+     ++XXXXXXXXXXXX+
  40          XXXXX+      +X++++XXXXXXX++
  30           XX++       XXXXXXXXXXXXXX+
  20            X++      XXXXXXX +X+X++
  10             ++++    XXXXXX+  +++++
   0              +XX+     XX+      ++++
 -10              +XXXX    +X+         ++
 -20               XXX+     XX        XXXX
 -30               XXX      X+        XXXX
 -40               X                     + +
 -50               X
 -60
 -70    XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
 -80    #####################################
 -90    #####################################
```

Table 4. Surface albedo model. Key: # = 0.75; X = 0.21; + = 0.14; blank = 0.07

land, half sea and half land, all land or snow covered: no account is taken of daily or seasonal variations of albedo (Table 4). Cloud amounts of 0.25, 0.625 or 0.875 are allocated to each 10° latitude x 10° longitude area for each of the four months (Table 5): no account is taken of daily variations of cloudiness.

6. Relations for heating rate components

The double expansion of J_a in terms of Fourier components of time (G.M.T.) t and longitude ϕ and of Hough functions of colatitude θ may be written (Groves, 1980)

$$J_a = Rl\left[\sum_{s} J_0^{s*}(\mu)\, e^{is\phi} + \sum_{m=1}^{\infty}\sum_{s=-\infty}^{\infty}\sum_{n} J_{m,n}^{s*}\, \Theta_{m,n}^{s}(\mu)\, e^{i(mt+s\phi)}\right] \tag{6.1}$$

where

$$\mu = \cos\theta \tag{6.2}$$

and t and ϕ are in radians. m = 1,2... relate to the diurnal, semi-diurnal ... components of oscillation and s is a longitudinal wave number. The summation with respect to n is taken over all members of the set of Hough functions $\Theta_{m,n}^{s}$ of Laplace's tidal equation for given m ($\neq 0$) and s. It may be shown using (6.1) that

January

```
Lat   180 W    90         0      90      180 E
        :        :        :        :        :
  90    +++++++++++++++++++++++++++++++++++++
  80           ++++++++++++++++++++
  70    +++++++++++++++++++++++++++++++++++++
  60    ##+++##++++#######+#########    ++###
  50    ######+++++++#####  #######+ #+++####
  40    +#####++ ++####### +###+ +++   +####+
  30    #+##++#  +++++++++         + + #++++#
  20     +   ++       ++              +++++
  10    ++   +++ ++   ++        ++ ++++#+++++
   0          ++ ++++++  ++#++  +++#+#+++
 -10    +++      ++###+ ++++##+  ++++++++#+++
 -20    ++++++++ ++ ++++#+## ++    +++   ++#+
 -30    +++++++ +++ +++#+++   +++  +#+   ++++
 -40    #######+###  ++++##+ +++####+###++++#
 -50    ####+######+++#########+##+#######+##
 -60    #####++########################+#####
 -70    +++++++++++++++++++++++++++++++++++++
 -80    +++++++++++++++++++++++++++++++++++++
 -90    +++++++++++++++++++++++++++++++++++++
```

April

```
Lat   180 W    90         0      90      180 E
        :        :        :        :        :
  90    +++++++++++++++++++++++++++++++++++++
  80    +++++++++++++++++++++++++++++++++++++
  70    +++++++++++++++++++++++++++++++++++++
  60    #######  +++####+ +##+     +++++#+ ##
  50    ###++#  +++++####++##+    #+ ++ #++##
  40    #####+   +#+##+++++   #+ ++   ++++###
  30    +++++#+  + ++#+             ++##+++++
  20       ++#+       +              +
  10    +++++#+#+#++  +++ +        ++ ++  +++
   0             +#+#++#+++#+#+ +++++##++#
 -10    + ++   +++ ++ +  ++#  ++  ++   ++++++
 -20    + +++++ +## + ++++#+  ++  +++     +++
 -30    +++#++#+###   ++##++   ++ +#++    +++
 -40     +#########  ++###+##+++####+#++++##
 -50    ###########++####+#####+#############
 -60    ###########+++#######################
 -70    +++++++++++++++++++++++++++++++++++++
 -80    +++++++++++++++++++++++++++++++++++++
 -90    +++++++++++++++++++++++++++++++++++++
```

Table 5. <u>Cloud amount models for January (above) and April (below) based mainly on the 1962-3 data of Clapp (1964). Key: # = 0.875; + = 0.625; blank = 0.25</u>

July

```
 Lat  180 W     90        0        90       180 E
        :        :        :        :        :
  90    +++++++++++++++++++++++++++++++++++++
  80    +++++++++++++++++++++++++++++++++++++
  70    +++++++++++++++++++++++++++++++++++++
  60    #############+####+########+    +++##
  50    ######  ++ ++++##+ #++  ++  ##++#####
  40    ##+#++     ++++++              ++####
  30    +++++++  ++#    +         +###+     +
  20      ++##+ +     ++         +###+ +++
  10    ++++++##+++++++#++++ +  ++++#+#+ #+++
   0            +###++    +++++ ++++#+##++
 -10    ++      ++#   + ++##   ++ ++#    +##+
 -20     +++++++#+#   ++++++   ++ +++     ++
 -30    +++++#####+   ++++++  ++++++++   ++++
 -40    +########## #########+#######+###++++
 -50    #### ####+ ###################+######
 -60    ######+++############################
 -70    +++++++++++++++++++++++++++++++++++++
 -80    +++++++++++++++++++++++++++++++++++++
 -90    +++++++++++++++++++++++++++++++++++++
```

October

```
 Lat  180 W     90        0        90       180 E
        :        :        :        :        :
  90    +++++++++++++++++++++++++++++++++++++
  80    +++++++++++++++++++++++++++++++++++++
  70    #####################################
  60    ########+++###++#+######++##++# ++++#
  50    ######  +#########+++++      +++##+##
  40    ####++++++++#+++++        +   ++#####
  30    +++++#+  ++++++++         +++++++++++
  20    +++++##+ +  ++ +            +#+++++++
  10    ##++++##++#+ +#++#++     +++++++#+++#
   0            +##+++   +++#++ ++####++#++
 -10    #++++  +##+++++ +###   +++#++    +++#
 -20    +#+++++++##  +#+###     +++ +      ++
 -30    +++#+++###+  +#+#### ++ +++#++    +++
 -40    +#########+ +###################++#++
 -50    ######+###+++########################
 -60    #####################################
 -70    +++++++++++++++++++++++++++++++++++++
 -80    +++++++++++++++++++++++++++++++++++++
 -90    +++++++++++++++++++++++++++++++++++++
```

Table 5. <u>(continued) July and October</u>

$$J_0^s(\mu) = \frac{1}{4\pi^2}\int_0^{2\pi}\int_0^{2\pi} J_a(\mu,\phi,t)\,dt\,d\phi \qquad (s=0)$$

$$= \frac{1}{2\pi^2}\int_0^{2\pi}\int_0^{2\pi} J_a(\mu,\phi,t)\,e^{is\phi}\,dt\,d\phi \qquad (s\neq 0) \tag{6.3}$$

and on using the orthogonality properties of $\Theta_{m,n}^s$ that for m $\neq$ 0

$$J_{m,n}^s = \frac{1}{2\pi^2}\int_{-1}^{1}\int_0^{2\pi}\int_0^{2\pi} J_a(\mu,\phi,t)\,\Theta_{m,n}^s(\mu)\,e^{i(mt+s\phi)}\,dt\,d\phi\,d\mu \tag{6.4}$$

We neglect cloud edge effects and take

$$J_a = (1-\kappa)\,J_{a1} + \kappa\,J_{a2} \tag{6.5}$$

where κ is the fraction of cloudy sky and J_{a1}, J_{a2} are given by (2.14) and (3.14) respectively. If t' is defined by

$$\pi + t' = t + \phi \tag{6.6}$$

spherical trigonometry gives

$$\cos\zeta = \cos\theta\,\sin\delta + \sin\theta\,\cos\delta\,\cos t' \tag{6.7}$$

where δ is solar declination. Equations (6.3), (6.4) then become

$$J_0^s(\mu) = \frac{S_0}{4\pi}\int_0^{2\pi} F_0 \, d\phi \qquad (s = 0)$$
$$= \frac{S_0}{2\pi}\int_0^{2\pi} F_0 \, e^{is\phi}\, d\phi \qquad (s \neq 0) \qquad (6.8)$$

$$J_{m,n}^s = \frac{S_0}{2\pi}\int_{-1}^{1}\int_0^{2\pi} F_m \, \Theta_{m,n}^s \, e^{i(s-m)\phi}\, d\phi \, d\mu \qquad (6.9)$$

where

$$(-)^m F_m = \frac{q\eta^c}{\pi}\Big\{(1-\kappa)\int_{-t_0}^{t_0}\left[M A_1(y) + \tfrac{5}{3} R A_1(y')\right]\cos\zeta \cos mt' \, dt'$$
$$+ \kappa Z \int_{-t_0}^{t_0} \cos\zeta \cos mt' \, dt' \Big\} \qquad (6.10)$$

and $-t_0$, t_0 are the values of t' at sunrise and sunset respectively. The factor cos mt' replaces $e^{imt'}$ in (6.10) as y and y', as well as $\cos\zeta$ and M, are even functions of t' when q is an even function of t' or, more particularly, is independent of t' as here (§ 4).

7. Water vapour heating rates

7.1 Mean heating

In preliminary calculations (Figs. 3 to 5) the effects on heating profiles of different values of absorption coefficients and scattering parameters have been investigated by evaluating mean heating rates J_o^o/c_p in ^oC/day for April with specific humidities appropriate to longitude 0^o, $R = 0.14$ and 100 per cent cloud in all cases; c_p being the specific heat of air at constant pressure.

Fig. 3 shows equatorial heating profiles for $\sigma = 20$, 40 and 80 cm^{-1}, the results having been calculated from (6.8) with $\kappa = 1$ in (6.10). The continuous curves show that for this range of values of σ, the heating below 8 km varies by up to 0.3^oC/day whereas the variation is imperceptible above this height. The equatorial heating profile with absorption coefficients k_i (Table 3) is compared in Fig. 3 with that for the same σ (= 40 cm^{-1}) and absorption coefficients $1.4k_i$, the latter being adopted in the main calculations below to allow for additional absorption by water droplets (§ 5). With the higher absorption, Fig. 3 shows that heating rates increase at all heights by at most 0.2^oC/day.

The effect of variations ± 0.025 from the adopted value $f = 0.925$ are shown in Fig. 4. Such a range of variation corresponds to probabilities of 5 to 10 per cent back-scatter

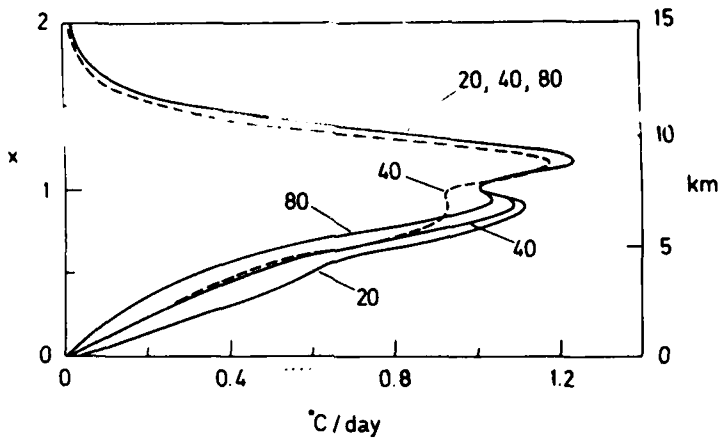

Fig. 3 Equatorial mean heating rates J_o^o/c_p for April with 100 per cent cloud and specific humidities equal to longitude 0^o values. Key: - - - - absorption coefficients k_i from Table 3; —— absorption coefficients 1.4 k_i. Values of σ (cm^{-1}) are marked on the curves. $x = \ln(p_o/p)$.

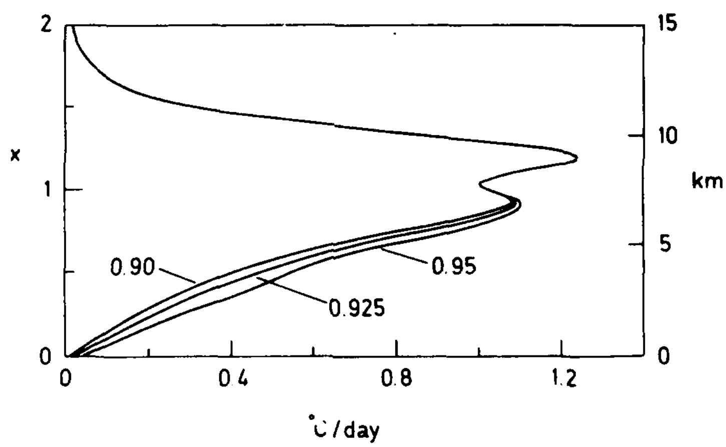

Fig. 4 Equatorial mean heating rates J_o^o/c_p for April with 100 per cent cloud, specific humidities equal to longitude 0^o values, σ = 40 cm^{-1} and absorption coefficients 1.4 k_i. Values of f are marked on the curves. $x = \ln(p_o/p)$.

in a scattering event. Fig. 4 shows a small effect of less than 0.15°C/day on heating rates below 7 km.

Fig. 5 compares equatorial heating profiles obtained with $\sigma = 40\ cm^{-1}$, $f = 0.925$ and different sets of absorption coefficients k_i. The absorption coefficients of Somerville et al., (1974) give results in close agreement with those obtained with the absorption coefficients of Lacis and Hansen (1974), which is understandable as both sets of coefficients were derived from the same absorption relation (2.3). By (2.3) and (3.2), the 6 coefficients of Somerville et al., (1974) approximate dA/dy, as obtained from (2.15), to within 16 per cent for $10^{-2} \leqslant y \leqslant 10$ cm, whereas the 8 coefficients of Lacis and Hansen approximate it to within 1 per cent. With the absorption coefficients of Tiedtke and Geleyn (1975) a similar heating profile is again derived, but with [illegible]se of Kerschens et al., (1976) and Welch et al., (1976) maximum heating rates of close to 1.6°C/day are obtained at 8 to 9 km compared with 1.1 to 1.2°C/day for the three other sets of coefficients.

Of the various data adopted, the absorption coefficients appear to give rise to the greatest uncertainty in calculated heating rates. With the 6 coefficients of Somerville et al., (1974) for cloudy skies and (2.15) for clear skies computing times were satisfactorily short and these absorption data have

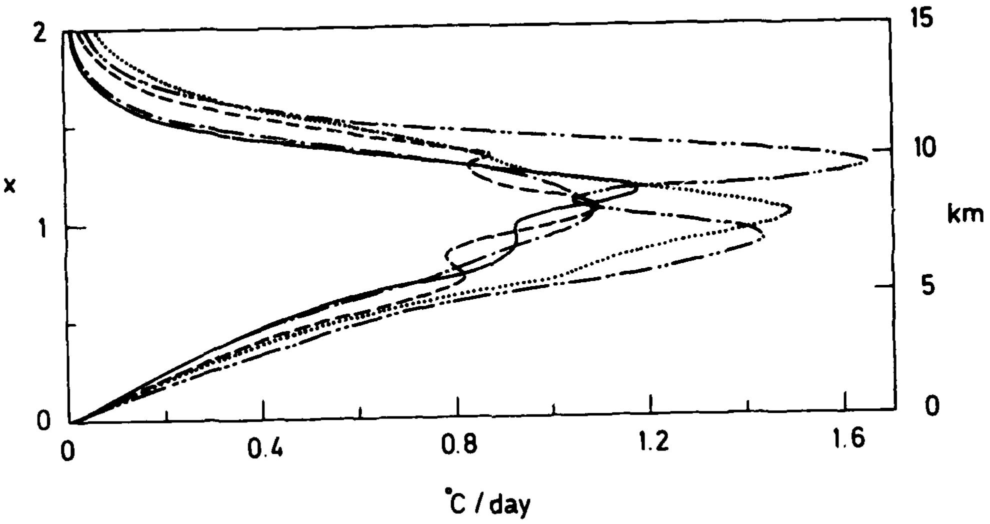

Fig. 5 Equatorial mean heating rates J_o^o/c_p for April with 100 per cent cloud, specific humidities equal to longitude 0^o values, $\sigma = 40\ cm^{-1}$, f = 0.925 and various sets of absorption coefficients k_i. Key: —— Somerville et al. (1974); -.-.- Lacis and Hansen (1974); -..-..- Welch et al. (1976); - - - - Tietdke and Geleyn (1975); .... Kerschens et al. (1976). $x = \ln(p_o/p)$.

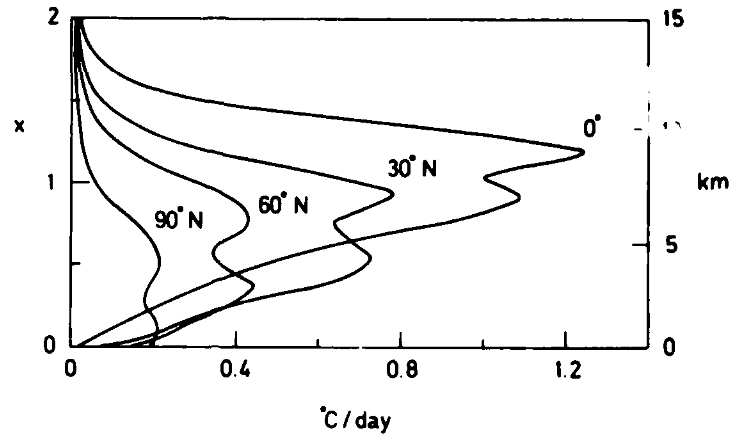

Fig. 6 Mean heating profiles at different latitudes for April with 100 per cent cloud and specific humidities equal to longitude 0^{o} values. $x = \ln(p_o/p)$.

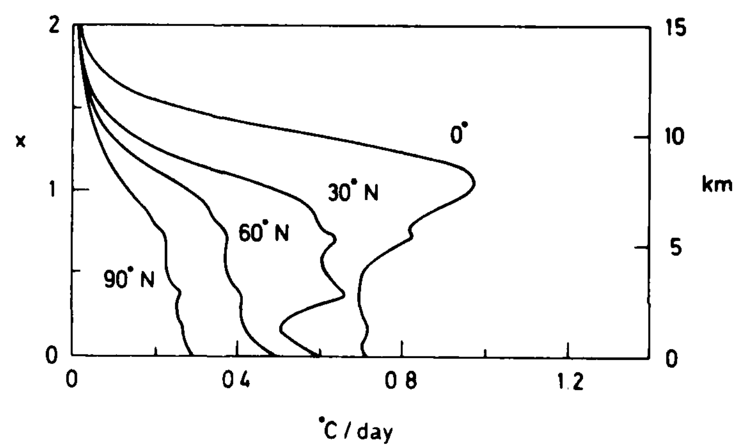

Fig. 7 As Fig. 6 but with no cloud.

been used in all subsequent calculations. An alternative choice would be the 8 coefficients of Lacis and Hansen (1974) for cloudy skies as the accuracy of the series fit to (2.15) is then considerably improved as discussed above, but as Fig. 5 shows the effect on heating rates is small compared with the uncertainty in the absorption data itself.

A final comparison has been made between heating profiles in cloudy and clear skies. Fig. 6 shows the variation of heating with latitude for the adopted absorption and scattering data and 100 per cent cloud cover. The 0° latitude profile also appears in Figs. 3 and 4. Fig. 7 shows the corresponding profiles for clear skies calculated from (6.8) with $\kappa = 0$ in (6.10). The main effect of cloudiness is to reduce heating rates in the lower troposphere and to increase heating rates at greater heights where radiation fluxes are enhanced by back-scattered radiation.

7.2 Diurnal Hough components

Diurnal Hough components of heating have been calculated from (6.9) for January, April, July and October using the specific humidity model described in § 4 and the atmospheric and surface albedo data of § 5. Values of solar declination and Sun-Earth distance are taken for the middle day of each of these months. Hough functions are normalized with a choice

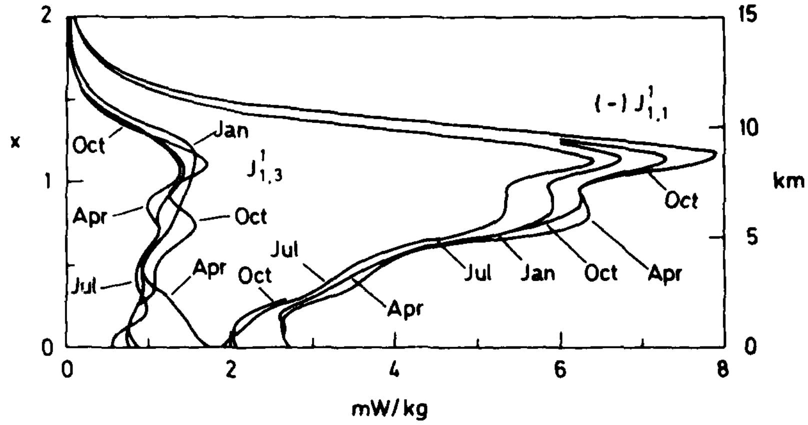

Fig. 8 Height profiles of Hough components of heating $J^1_{1,n}$ for n = 1, 3. $x = \ln(p_o/p)$.

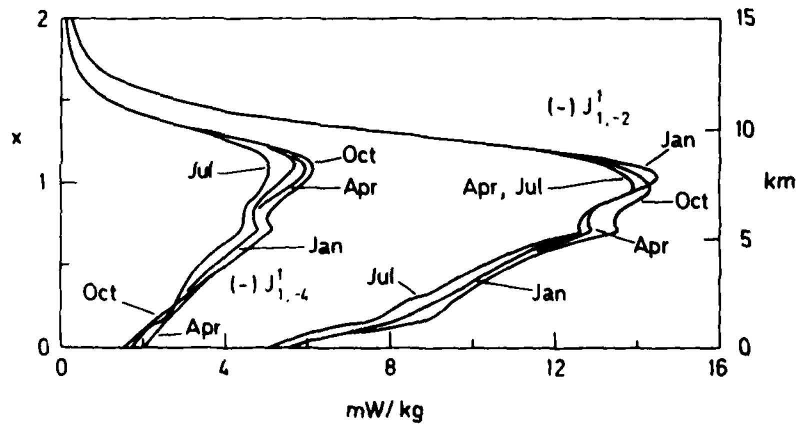

Fig. 9 Height profiles of Hough components of heating $J^1_{1,n}$ for n = -2, -4. $x = \ln(p_o/p)$.

of sign such that values are positive at the equator for equatorially symmetric modes or increase with latitude at the equator for equatorially anti-symmetric modes. When s = m, it follows from (6.9) that $J^s_{m,n}$ is real.

The results obtained for the symmetric components $J^1_{1,1}$ and $J^1_{1,3}$ are shown in Fig. 8 which supersedes a previous plot of these quantities calculated for cloudless skies (Groves, 1977). The effect of scattering nearly doubles $J^1_{1,1}$ at 8 km and approximately halves it near the surface. Results are plotted in Fig. 9 for $J^1_{1,-2}$, $J^1_{1,-4}$ which are the two leading members of the sequence of symmetric modes of high latitude importance.

Fig. 10 shows the anti-symmetric component $J^1_{1,-1}$ for which the January and July profiles are similar with a reversal of sign. Values obtained for $J^1_{1,-3}$, $J^1_{1,-5}$ are relatively small being less than 0.8, 0.4 mW/kg respectively for all heights and seasons, and hence $J^1_{1,-1}$ accounts for the main part of the high-latitude asymmetry. Values of $J^1_{1,-1}$ and $J^1_{1,-3}$ are given in Table 6.

Longitudal variations of water vapour, cloud cover and to some extent surface albedo give rise to non-migrating Hough components of heating. For latitudes greater than 35° N or S specific humidities have been modelled using the ratios in Table 2 which are not longitude dependent, and therefore it

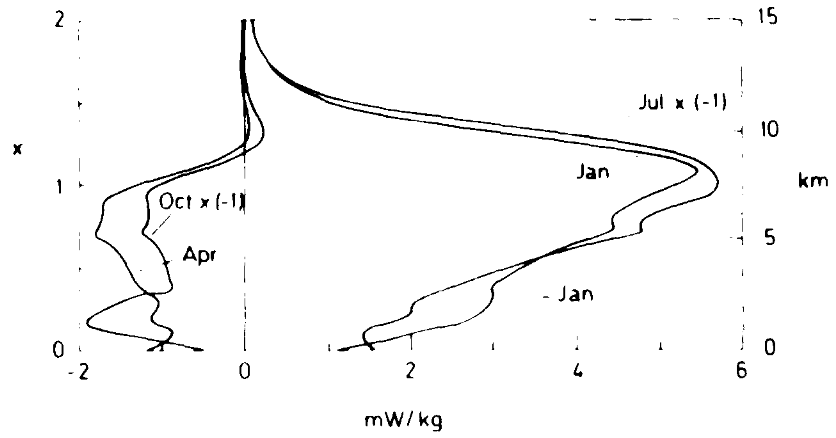

Fig. 10 Height profiles of Hough components of heating $J^1_{1,-1}$. $x = \ln(p_o/p)$.

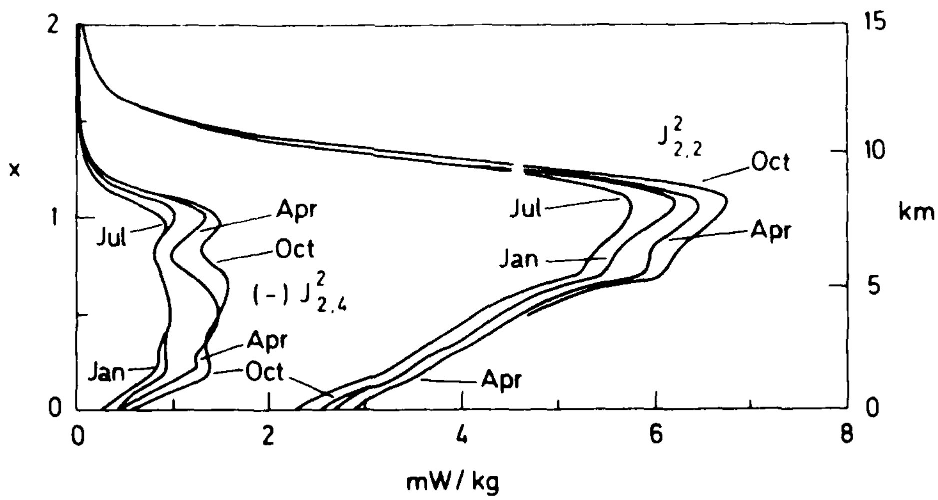

Fig. 11 Height profiles of Hough components of heating $J^2_{2,n}$ for n = 2, 4. $x = \ln(p_o/p)$.

	(1,1,1)				(1,1,2)			
	mW/kg				mW/kg			
x	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct
0.00	-2.70	-2.70	-1.92	-2.06	-0.86	-0.78	0.46	-0.01
0.05	-2.61	-2.64	-2.01	-2.02	-0.88	-0.73	0.41	-0.08
0.10	-2.60	-2.65	-2.13	-2.04	-0.91	-0.70	0.37	-0.11
0.15	-2.60	-2.63	-2.24	-2.07	-0.92	-0.60	0.41	-0.07
0.20	-2.68	-2.60	-2.33	-2.17	-0.82	-0.43	0.47	-0.04
0.25	-2.88	-2.76	-2.54	-2.44	-0.73	-0.37	0.47	-0.04
0.30	-3.15	-2.99	-2.81	-2.81	-0.60	-0.29	0.47	-0.04
0.35	-3.46	-3.20	-3.09	-3.25	-0.38	-0.12	0.52	0.00
0.40	-3.59	-3.35	-3.22	-3.44	-0.25	-0.04	0.46	0.01
0.45	-3.70	-3.51	-3.34	-3.58	-0.17	-0.00	0.39	-0.01
0.50	-3.83	-3.71	-3.49	-3.73	-0.13	0.02	0.35	-0.00
0.55	-4.04	-3.99	-3.69	-3.94	-0.11	0.03	0.33	0.01
0.60	-4.36	-4.44	-4.00	-4.26	-0.08	0.04	0.28	0.05
0.65	-4.82	-5.08	-4.41	-4.74	-0.01	0.06	0.17	0.11
0.70	-5.39	-5.88	-4.90	-5.34	0.16	0.12	-0.05	0.17
0.75	-5.68	-6.20	-5.15	-5.78	0.36	0.22	-0.27	0.15
0.80	-5.86	-6.36	-5.30	-6.09	0.56	0.34	-0.47	0.08
0.85	-5.91	-6.34	-5.33	-6.22	0.71	0.45	-0.55	-0.02
0.90	-5.90	-6.29	-5.33	-6.24	0.74	0.48	-0.50	-0.08
0.95	-5.84	-6.22	-5.34	-6.23	0.60	0.39	-0.34	-0.07
1.00	-5.86	-6.30	-5.44	-6.32	0.40	0.26	-0.20	0.05
1.05	-6.14	-6.68	-5.79	-6.76	0.33	0.20	-0.22	0.17
1.10	-6.55	-7.14	-6.21	-7.41	0.48	0.30	-0.44	0.18
1.15	-6.74	-7.30	-6.37	-7.86	0.76	0.48	-0.70	0.08
1.20	-6.49	-6.98	-6.05	-7.73	0.99	0.64	-0.85	-0.05
1.25	-5.81	-6.21	-5.31	-7.00	1.07	0.72	-0.85	-0.15
1.30	-4.86	-5.19	-4.37	-5.90	0.98	0.69	-0.73	-0.18
1.35	-3.84	-4.08	-3.41	-4.66	0.81	0.58	-0.57	-0.17
1.40	-2.95	-3.16	-2.60	-3.58	0.63	0.49	-0.43	-0.15
1.45	-2.20	-2.42	-1.93	-2.66	0.46	0.42	-0.30	-0.11
1.50	-1.59	-1.83	-1.40	-1.92	0.32	0.36	-0.21	-0.08
1.55	-1.15	-1.37	-1.02	-1.38	0.22	0.29	-0.14	-0.06
1.60	-0.83	-1.01	-0.74	-0.99	0.14	0.23	-0.09	-0.04
1.65	-0.60	-0.73	-0.54	-0.70	0.09	0.16	-0.06	-0.03
1.70	-0.44	-0.52	-0.40	-0.51	0.06	0.11	-0.04	-0.02
1.75	-0.32	-0.37	-0.29	-0.37	0.04	0.07	-0.02	-0.01
1.80	-0.24	-0.27	-0.22	-0.27	0.02	0.04	-0.01	-0.01
1.85	-0.18	-0.20	-0.17	-0.20	0.01	0.03	-0.01	-0.01
1.90	-0.14	-0.15	-0.14	-0.16	0.01	0.02	-0.01	-0.00
1.95	-0.11	-0.12	-0.11	-0.12	0.00	0.01	-0.00	-0.00
2.00	-0.09	-0.10	-0.09	-0.10	0.00	0.01	-0.00	-0.00

Table [illegible]. Hough components of heating $J^{m}_{m,n}$ associated with mode (m,m,n), m = 1, 2. x = ln (p_0/p)

x	(1,1,3) mW/kg Jan	Apr	Jul	Oct	(1,1,-1) mW/kg Jan	Apr	Jul	Oct
0.00	0.88	1.73	0.54	0.79	1.10	-1.13	-1.55	0.51
0.05	0.80	1.60	0.58	0.72	1.63	-0.99	-1.47	1.04
0.10	0.75	1.52	0.65	0.71	2.06	-0.89	-1.43	1.47
0.15	0.76	1.48	0.87	0.74	2.52	-1.00	-1.60	1.90
0.20	0.84	1.40	1.01	0.79	2.77	-1.16	-1.94	1.88
0.25	0.88	1.32	0.99	0.89	2.88	-1.07	-2.00	1.71
0.30	0.92	1.24	0.95	1.00	2.97	-1.02	-2.10	1.44
0.35	0.92	1.06	0.85	1.07	2.92	-1.22	-2.40	0.96
0.40	0.90	0.97	0.82	1.07	3.02	-1.33	-2.68	0.89
0.45	0.91	0.92	0.83	1.06	3.17	-1.36	-2.90	0.92
0.50	0.94	0.90	0.87	1.08	3.34	-1.41	-3.16	0.94
0.55	0.99	0.93	0.92	1.15	3.54	-1.47	-3.47	0.97
0.60	1.05	1.00	0.98	1.27	3.80	-1.56	-3.84	1.02
0.65	1.13	1.06	1.04	1.41	4.09	-1.67	-4.26	1.10
0.70	1.22	1.10	1.09	1.54	4.39	-1.83	-4.72	1.22
0.75	1.27	1.06	1.09	1.53	4.42	-1.74	-4.78	1.17
0.80	1.31	1.00	1.10	1.46	4.45	-1.71	-4.90	1.14
0.85	1.34	0.97	1.13	1.33	4.53	-1.70	-5.12	1.14
0.90	1.37	1.01	1.21	1.24	4.73	-1.70	-5.46	1.18
0.95	1.41	1.14	1.31	1.25	5.00	-1.56	-5.70	1.17
1.00	1.43	1.28	1.38	1.40	5.23	-1.30	-5.73	1.06
1.05	1.48	1.36	1.41	1.61	5.42	-0.99	-5.68	0.84
1.10	1.54	1.37	1.41	1.71	5.45	-0.65	-5.61	0.51
1.15	1.58	1.31	1.37	1.63	5.22	-0.35	-5.48	0.18
1.20	1.55	1.21	1.28	1.42	4.73	-0.13	-5.19	-0.06
1.25	1.42	1.07	1.13	1.15	4.04	0.01	-4.67	-0.19
1.30	1.21	0.91	0.95	0.89	3.28	0.06	-3.97	-0.23
1.35	0.97	0.76	0.76	0.67	2.54	0.05	-3.17	-0.21
1.40	0.76	0.60	0.59	0.50	1.93	0.04	-2.46	-0.17
1.45	0.57	0.44	0.44	0.37	1.44	0.02	-1.84	-0.12
1.50	0.41	0.30	0.32	0.27	1.05	0.01	-1.34	-0.08
1.55	0.30	0.20	0.24	0.20	0.77	-0.00	-0.96	-0.04
1.60	0.22	0.14	0.17	0.15	0.57	-0.01	-0.69	-0.02
1.65	0.16	0.10	0.13	0.11	0.42	-0.02	-0.50	-0.00
1.70	0.11	0.07	0.09	0.08	0.31	-0.02	-0.36	0.01
1.75	0.08	0.06	0.07	0.06	0.23	-0.03	-0.26	0.02
1.80	0.06	0.05	0.05	0.05	0.18	-0.03	-0.20	0.02
1.85	0.05	0.04	0.04	0.04	0.14	-0.03	-0.15	0.02
1.90	0.04	0.03	0.03	0.03	0.11	-0.03	-0.12	0.02
1.95	0.03	0.02	0.03	0.03	0.09	-0.03	-0.10	0.02
2.00	0.02	0.02	0.02	0.02	0.08	-0.03	-0.08	0.02

Table 6. (continued)

x	(1,1,-2) mW/kg Jan	Apr	Jul	Oct	(1,1,-3) mW/kg Jan	Apr	Jul	Oct
0.00	-5.35	-5.69	-4.93	-5.18	-0.76	0.12	0.24	-0.61
0.05	-6.23	-6.41	-5.54	-6.26	-0.77	0.15	0.39	-0.54
0.10	-6.97	-7.01	-6.12	-7.22	-0.78	0.18	0.50	-0.52
0.15	-7.90	-7.98	-7.06	-8.47	-0.77	0.27	0.57	-0.52
0.20	-8.52	-8.78	-7.84	-9.14	-0.71	0.37	0.55	-0.47
0.25	-8.85	-9.12	-8.16	-9.37	-0.68	0.40	0.59	-0.40
0.30	-9.21	-9.51	-8.52	-9.58	-0.63	0.43	0.64	-0.33
0.35	-9.73	-10.20	-9.13	-9.87	-0.59	0.48	0.72	-0.31
0.40	-10.10	-10.58	-9.55	-10.24	-0.55	0.46	0.75	-0.28
0.45	-10.38	-10.80	-9.87	-10.58	-0.50	0.42	0.73	-0.24
0.50	-10.69	-11.05	-10.24	-10.96	-0.42	0.40	0.69	-0.22
0.55	-11.02	-11.33	-10.65	-11.39	-0.32	0.39	0.60	-0.22
0.60	-11.45	-11.73	-11.18	-11.96	-0.19	0.40	0.48	-0.26
0.65	-11.98	-12.24	-11.83	-12.65	-0.05	0.42	0.34	-0.32
0.70	-12.59	-12.87	-12.59	-13.49	0.09	0.47	0.20	-0.40
0.75	-12.60	-12.80	-12.58	-13.45	0.12	0.49	0.15	-0.42
0.80	-12.69	-12.84	-12.70	-13.50	0.07	0.48	0.15	-0.40
0.85	-12.94	-13.03	-12.97	-13.68	-0.03	0.42	0.16	-0.33
0.90	-13.46	-13.45	-13.48	-14.08	-0.12	0.35	0.13	-0.21
0.95	-14.02	-13.80	-13.84	-14.33	-0.14	0.28	0.07	-0.06
1.00	-14.37	-13.88	-13.85	-14.30	-0.04	0.24	-0.01	0.04
1.05	-14.49	-13.72	-13.70	-14.11	0.18	0.23	-0.11	0.06
1.10	-14.19	-13.17	-13.35	-13.62	0.43	0.26	-0.25	-0.01
1.15	-13.32	-12.15	-12.66	-12.67	0.63	0.29	-0.43	-0.11
1.20	-11.90	-10.72	-11.55	-11.26	0.72	0.31	-0.59	-0.19
1.25	-10.12	-9.05	-10.06	-9.54	0.69	0.30	-0.66	-0.22
1.30	-8.25	-7.36	-8.36	[illegible]	[illegible]	0.26	-0.63	-0.21
1.35	-6.47	-5.80	-6.64	-6.08	0.46	0.21	-0.53	-0.18
1.40	-5.00	-4.51	-5.15	-4.69	0.34	0.17	-0.42	-0.15
1.45	-3.79	-3.47	-3.90	-3.57	0.24	0.13	-0.31	-0.12
1.50	-2.84	-2.64	-2.90	-2.68	0.15	0.10	-0.21	-0.09
1.55	-2.13	-2.01	-2.15	-2.02	0.10	0.08	-0.13	-0.06
1.60	-1.60	-1.53	-1.60	-1.53	0.06	0.06	-0.08	-0.05
1.65	-1.22	-1.17	-1.19	-1.17	0.03	0.05	-0.05	-0.04
1.70	-0.94	-0.90	-0.91	-0.91	0.01	0.04	-0.02	-0.03
1.75	-0.73	-0.70	-0.70	-0.71	0.00	0.03	-0.01	-0.02
1.80	-0.58	-0.56	-0.55	-0.57	-0.00	0.03	0.00	-0.02
1.85	-0.47	-0.46	-0.44	-0.47	-0.01	0.02	0.01	-0.01
1.90	-0.39	-0.38	-0.36	-0.39	-0.01	0.02	0.01	-0.01
1.95	-0.33	-0.33	-0.31	-0.34	-0.01	0.02	0.01	-0.01
2.00	-0.29	-0.28	-0.26	-0.29	-0.01	0.02	0.01	-0.01

Table 6. (continued)

x	(1,1,-4) mW/kg				(1,1,-6) mW/kg			
	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct
0.00	-1.68	-2.01	-1.75	-1.43	-1.77	-1.63	-1.50	-1.54
0.05	-1.87	-2.19	-1.90	-1.68	-1.52	-1.50	-1.35	-1.37
0.10	-2.04	-2.36	-2.08	-1.91	-1.42	-1.47	-1.31	-1.33
0.15	-2.32	-2.59	-2.42	-2.22	-1.46	-1.53	-1.44	-1.36
0.20	-2.58	-2.77	-2.68	-2.48	-1.53	-1.56	-1.55	-1.35
0.25	-2.72	-2.90	-2.77	-2.72	-1.52	-1.54	-1.53	-1.37
0.30	-2.90	-3.07	-2.88	-2.98	-1.53	-1.54	-1.54	-1.44
0.35	-3.18	-3.27	-2.99	-3.30	-1.59	-1.58	-1.56	-1.58
0.40	-3.36	-3.48	-3.10	-3.53	-1.62	-1.63	-1.58	-1.66
0.45	-3.53	-3.69	-3.22	-3.75	-1.67	-1.73	-1.61	-1.77
0.50	-3.73	-3.92	-3.38	-4.00	-1.76	-1.88	-1.66	-1.94
0.55	-3.94	-4.14	-3.56	-4.25	-1.88	-2.07	-1.73	-2.13
0.60	-4.20	-4.38	-3.79	-4.53	-2.04	-2.27	-1.83	-2.35
0.65	-4.49	-4.60	-4.07	-4.82	-2.22	-2.46	-1.96	-2.55
0.70	-4.78	-4.82	-4.39	-5.10	-2.42	-2.61	-2.13	-2.69
0.75	-4.77	-4.74	-4.40	-5.04	-2.44	-2.51	-2.17	-2.60
0.80	-4.73	-4.72	-4.41	-5.04	-2.41	-2.40	-2.17	-2.50
0.85	-4.74	-4.81	-4.48	-5.13	-2.36	-2.34	-2.17	-2.45
0.90	-4.87	-5.08	-4.66	-5.39	-2.35	-2.40	-2.21	-2.52
0.95	-5.09	-5.42	-4.86	-5.69	-2.38	-2.54	-2.29	-2.65
1.00	-5.34	-5.71	-4.97	-5.92	-2.46	-2.73	-2.35	-2.82
1.05	-5.59	-5.90	-5.04	-6.10	-2.58	-2.90	-2.39	-2.99
1.10	-5.70	-5.88	-5.03	-6.11	-2.66	-2.97	-2.39	-3.08
1.15	-5.53	-5.56	-4.89	-5.83	-2.62	-2.87	-2.32	-3.00
1.20	-5.06	-4.98	-4.57	-5.26	-2.42	-2.61	-2.16	-2.74
1.25	-4.37	-4.24	-4.06	-4.48	-2.10	-2.24	-1.92	-2.36
1.30	-3.58	-3.45	-3.41	-3.64	-1.72	-1.84	-1.62	-1.92
1.35	-2.81	-2.70	-2.72	-2.83	-1.35	-1.44	-1.29	-1.50
1.40	-2.16	-2.08	-2.12	-2.16	-1.03	-1.11	-1.00	-1.14
1.45	-1.62	-1.57	-1.60	-1.61	-0.77	-0.84	-0.75	-0.85
1.50	-1.20	-1.17	-1.18	-1.18	-0.56	-0.63	-0.55	-0.63
1.55	-0.88	-0.87	-0.86	-0.86	-0.41	-0.47	-0.40	-0.46
1.60	-0.65	-0.64	-0.63	-0.63	-0.29	-0.34	-0.29	-0.34
1.65	-0.48	-0.47	-0.46	-0.46	-0.21	-0.25	-0.21	-0.25
1.70	-0.36	-0.35	-0.35	-0.34	-0.16	-0.19	-0.15	-0.18
1.75	-0.27	-0.26	-0.26	-0.26	-0.12	-0.14	-0.11	-0.14
1.80	-0.21	-0.20	-0.20	-0.20	-0.09	-0.11	-0.09	-0.11
1.85	-0.17	-0.15	-0.16	-0.15	-0.07	-0.08	-0.07	-0.08
1.90	-0.13	-0.12	-0.13	-0.12	-0.05	-0.07	-0.05	-0.07
1.95	-0.11	-0.10	-0.10	-0.10	-0.04	-0.05	-0.04	-0.06
2.00	-0.09	-0.08	-0.09	-0.08	-0.04	-0.05	-0.04	-0.05

Table 6. (continued)

x	(2,2,2) mW/kg Jan	Apr	Jul	Oct	(2,2,3) mW/kg Jan	Apr	Jul	Oct
0.00	2.69	2.89	2.30	2.45	0.37	0.29	0.01	0.13
0.05	2.81	3.00	2.45	2.68	0.34	0.16	-0.16	0.01
0.10	2.96	3.15	2.64	2.94	0.31	0.07	-0.30	-0.08
0.15	3.22	3.42	2.98	3.30	0.27	0.02	-0.38	-0.17
0.20	3.43	3.64	3.24	3.54	0.23	-0.03	-0.36	-0.16
0.25	3.57	3.77	3.37	3.70	0.21	-0.10	-0.40	-0.11
0.30	3.74	3.94	3.52	3.90	0.19	-0.16	-0.42	-0.03
0.35	3.99	4.18	3.73	4.15	0.21	-0.17	-0.42	0.13
0.40	4.13	4.33	3.87	4.33	0.20	-0.17	-0.38	0.15
0.45	4.25	4.46	4.00	4.50	0.17	-0.17	-0.35	0.15
0.50	4.39	4.63	4.15	4.70	0.13	-0.17	-0.31	0.14
0.55	4.57	4.83	4.33	4.94	0.08	-0.17	-0.24	0.14
0.60	4.81	5.11	4.57	5.25	0.01	-0.16	-0.15	0.14
0.65	5.12	5.47	4.87	5.64	-0.09	-0.16	-0.04	0.14
0.70	5.47	5.89	5.23	6.09	-0.21	-0.15	0.10	0.14
0.75	5.54	5.93	5.28	6.17	-0.28	-0.19	0.19	0.17
0.80	5.60	5.95	5.34	6.23	-0.31	-0.21	0.25	0.20
0.85	5.67	5.99	5.43	6.30	-0.31	-0.23	0.29	0.21
0.90	5.81	6.12	5.58	6.44	-0.28	-0.25	0.33	0.20
0.95	5.97	6.27	5.70	6.55	-0.25	-0.30	0.34	0.16
1.00	6.09	6.37	5.74	6.62	-0.25	-0.39	0.34	0.14
1.05	6.20	6.45	5.77	6.71	-0.33	-0.49	0.36	0.19
1.10	6.19	6.37	5.72	6.72	-0.45	-0.61	0.42	0.31
1.15	5.90	6.01	5.47	6.46	-0.55	-0.70	0.52	0.43
1.20	5.29	5.35	4.96	5.84	-0.58	-0.72	0.58	0.50
1.25	4.46	4.48	4.23	4.96	-0.52	-0.68	0.56	0.50
1.30	3.54	3.57	3.40	3.97	-0.41	-0.59	0.47	0.44
1.35	2.68	2.72	2.58	3.02	-0.29	-0.47	0.34	0.36
1.40	1.99	2.04	1.92	2.25	-0.19	-0.37	0.23	0.28
1.45	1.44	1.51	1.39	1.65	-0.11	-0.28	0.14	0.21
1.50	1.03	1.11	0.99	1.18	-0.06	-0.21	0.07	0.15
1.55	0.74	0.82	0.71	0.85	-0.03	-0.16	0.03	0.10
1.60	0.54	0.60	0.51	0.62	-0.01	-0.12	0.00	0.07
.65	0.39	0.44	0.37	0.45	0.00	-0.09	-0.01	0.05
.70	0.29	0.32	0.28	0.34	0.01	-0.07	-0.02	0.04
1.75	0.22	0.24	0.21	0.26	0.01	-0.05	-0.02	0.02
1.80	0.17	0.18	0.16	0.20	0.01	-0.04	-0.02	0.02
1.85	0.14	0.14	0.13	0.16	0.01	-0.03	-0.02	0.01
1.90	0.11	0.11	0.10	0.13	0.01	-0.02	-0.02	0.01
1.95	0.09	0.10	0.09	0.11	0.01	-0.02	-0.02	0.01
2.00	0.08	0.08	0.07	0.09	0.01	-0.02	-0.02	0.01

Table 6. (continued)

x	(2,2,4) mW/kg Jan	Apr	Jul	Oct	(2,2,6) mW/kg Jan	Apr	Jul	Oct
0.00	-0.29	-0.49	-0.45	-0.57	-0.11	-0.19	-0.03	0.02
0.05	-0.44	-0.67	-0.54	-0.80	0.01	0.01	0.06	0.22
0.10	-0.56	-0.82	-0.64	-0.99	0.10	0.14	0.11	0.35
0.15	-0.73	-1.04	-0.82	-1.26	0.14	0.25	0.11	0.49
0.20	-0.84	-1.23	-0.93	-1.39	0.15	0.34	0.12	0.57
0.25	-0.85	-1.26	-0.92	-1.38	0.18	0.41	0.17	0.57
0.30	-0.85	-1.28	-0.91	-1.34	0.23	0.49	0.23	0.57
0.35	-0.91	-1.37	-0.91	-1.31	0.34	0.64	0.32	0.60
0.40	-0.96	-1.41	-0.93	-1.36	0.40	0.72	0.36	0.65
0.45	-0.98	-1.42	-0.94	-1.40	0.41	0.75	0.36	0.68
0.50	-1.01	-1.43	-0.95	-1.46	0.41	0.74	0.34	0.69
0.55	-1.01	-1.43	-0.95	-1.52	0.40	0.71	0.33	0.67
0.60	-0.99	-1.38	-0.93	-1.56	0.39	0.68	0.33	0.65
0.65	-0.95	-1.30	-0.91	-1.58	0.40	0.67	0.37	0.63
0.70	-0.90	-1.18	-0.89	-1.58	0.42	0.70	0.42	0.66
0.75	-0.81	-1.04	-0.81	-1.41	0.44	0.74	0.45	0.70
0.80	-0.77	-0.99	-0.78	-1.31	0.47	0.81	0.46	0.78
0.85	-0.80	-1.03	-0.81	-1.31	0.50	0.88	0.46	0.87
0.90	-0.90	-1.16	-0.88	-1.40	0.52	0.92	0.44	0.95
0.95	-1.01	-1.29	-0.92	-1.49	0.51	0.89	0.40	0.96
1.00	-1.05	-1.32	-0.88	-1.48	0.49	0.83	0.36	0.87
1.05	-0.97	-1.18	-0.73	-1.31	0.46	0.76	0.34	0.76
1.10	-0.76	-0.91	-0.51	-0.99	0.42	0.70	0.36	0.67
1.15	-0.52	-0.61	-0.31	-0.62	0.37	0.63	0.36	0.63
1.20	-0.31	-0.36	-0.18	-0.31	0.32	0.55	0.34	0.58
1.25	-0.17	-0.20	-0.12	-0.11	0.27	0.47	0.28	0.52
1.30	-0.10	-0.12	-0.09	-0.03	0.22	0.38	0.22	0.44
1.35	-0.07	-0.09	-0.07	-0.02	0.18	0.29	0.17	0.36
1.40	-0.06	-0.07	-0.06	-0.02	0.14	0.23	0.12	0.28
1.45	-0.06	-0.05	-0.04	-0.03	0.11	0.19	0.09	0.22
1.50	-0.06	-0.04	-0.03	-0.04	0.09	0.16	0.07	0.17
1.55	-0.06	-0.03	-0.03	-0.05	0.07	0.13	0.05	0.13
1.60	-0.05	-0.03	-0.02	-0.05	0.06	0.11	0.04	0.10
1.65	-0.05	-0.03	-0.02	-0.05	0.04	0.09	0.03	0.08
1.70	-0.04	-0.03	-0.02	-0.05	0.04	0.07	0.02	0.06
1.75	-0.04	-0.03	-0.02	-0.04	0.03	0.05	0.02	0.05
1.80	-0.03	-0.03	-0.02	-0.04	0.03	0.04	0.02	0.04
1.85	-0.03	-0.03	-0.02	-0.04	0.02	0.03	0.01	0.03
1.90	-0.03	-0.03	-0.02	-0.03	0.02	0.03	0.01	0.03
1.95	-0.03	-0.03	-0.01	-0.03	0.02	0.02	0.01	0.03
2.00	-0.02	-0.02	-0.01	-0.03	0.01	0.02	0.01	0.02

Table 6. (continued)

would be inappropriate to evaluate non-migrating modes of the negative sequence for which Hough functions predominate polewards of 45° latitude. On the other hand the positive sequence is confined to lower latitudes and $J^s_{1,1}$ has been evaluated for $|s - 1| = 1,...5$ corresponding to the first 5 harmonics of the longitudinal variation of terrestrial properties. Amplitudes $J^s_{1,1}$ are found to be small (less than 14 per cent) compared with $J^1_{1,1}$ and as $|s - 1|$ increases the largest values of $J^s_{1,1}$ with respect to height are found to decrease very slowly, indicating the need for a large number of small terms to represent the longitudinal variation in diurnal heating. Results obtained are shown in Table 7. As $|s - 1|$ and n increase, Hough functions change increasingly rapidly with latitude and it follows that the satisfactory evaluation of heating components would depend on adequate horizontal resolution of the terrestrial data.

7.3 Semi-diurnal Hough components

Results obtained from (6.9) for the leading symmetric components of heating $J^2_{2,2}$ and $J^2_{2,4}$ are plotted in Fig. 11. The introduction of cloud-related scattering nearly doubles $J^2_{2,2}$ at 8 km and approximately halves it near the surface. As $J^2_{2,4}$ is relatively small (Fig. 11) and values of $J^2_{2,6}$ are found to be even smaller being less than 1 mW/kg (Table 6), it follows that $J^2_{2,2}$ represents the main part of symmetrical

x	(1,0,1) mW/kg Jan	Apr	Jul	Oct	(1,2,1) mW/kg Jan	Apr	Jul	Oct
Real Part								
0.00	0.14	0.29	0.28	0.17	-0.01	0.12	0.17	0.04
0.10	0.17	0.24	0.10	0.12	0.10	0.18	0.08	0.01
0.20	0.17	0.22	-0.02	0.05	0.10	0.18	-0.12	-0.08
0.30	0.19	0.26	-0.08	-0.06	0.09	0.24	-0.12	-0.17
0.40	0.20	0.29	-0.08	-0.12	0.08	0.27	-0.10	-0.22
0.50	0.08	0.23	-0.04	-0.12	0.02	0.23	-0.06	-0.18
0.60	-0.11	0.20	0.04	-0.11	-0.07	0.24	0.01	-0.11
0.70	-0.32	0.16	0.30	0.01	-0.16	0.22	0.22	0.07
0.80	-0.26	-0.01	0.30	0.10	-0.09	0.05	0.29	0.21
0.90	-0.15	-0.09	0.27	0.13	-0.00	-0.05	0.29	0.25
1.00	-0.22	-0.33	-0.05	-0.14	-0.03	-0.16	0.11	0.08
1.10	-0.40	-0.75	-0.30	-0.27	-0.07	-0.44	0.06	0.13
1.20	-0.30	-0.95	-0.33	-0.17	0.09	-0.66	0.11	0.26
1.30	-0.13	-0.80	-0.27	-0.09	0.18	-0.60	0.09	0.23
1.40	-0.05	-0.53	-0.17	-0.05	0.14	-0.41	0.05	0.14
1.50	-0.02	-0.35	-0.10	-0.03	0.08	-0.29	0.02	0.07
1.60	-0.01	-0.21	-0.05	-0.02	0.04	-0.18	0.01	0.03
1.70	-0.01	-0.10	-0.03	-0.01	0.02	-0.08	0.00	0.01
1.80	-0.00	-0.04	-0.01	-0.01	0.01	-0.03	0.00	0.01
1.90	-0.00	-0.02	-0.01	-0.00	0.00	-0.01	-0.00	0.00
2.00	-0.00	-0.01	-0.00	-0.00	0.00	-0.01	-0.00	0.00
Imaginary Part								
0.00	-0.01	0.22	-0.06	-0.10	0.09	-0.24	0.11	-0.02
0.10	0.12	0.30	0.06	0.00	0.08	-0.19	0.09	-0.01
0.20	0.02	0.30	0.15	0.04	0.17	-0.14	0.09	0.04
0.30	-0.07	0.23	0.11	-0.01	0.17	-0.08	0.13	0.07
0.40	-0.21	-0.02	-0.05	-0.13	0.19	0.06	0.20	0.13
0.50	-0.14	-0.04	-0.00	-0.07	0.13	0.07	0.14	0.10
0.60	-0.13	-0.17	0.01	-0.03	0.12	0.16	0.12	0.08
0.70	-0.11	-0.37	0.07	0.04	0.06	0.27	0.03	0.01
0.80	0.04	-0.23	0.12	0.10	-0.13	0.07	-0.20	-0.11
0.90	0.17	-0.02	0.08	0.22	-0.29	-0.17	-0.32	-0.27
1.00	0.09	-0.10	-0.18	0.11	-0.19	-0.04	-0.12	-0.13
1.10	0.09	-0.17	-0.21	-0.05	-0.21	-0.01	-0.18	-0.02
1.20	0.31	0.04	-0.19	0.08	-0.52	-0.31	-0.45	-0.24
1.30	0.33	0.07	-0.26	0.15	-0.54	-0.33	-0.42	-0.31
1.40	0.21	0.00	-0.21	0.11	-0.35	-0.18	-0.25	-0.21
1.50	0.11	-0.11	-0.12	0.05	-0.18	0.02	-0.13	-0.11
1.60	0.05	-0.11	-0.06	0.02	-0.08	0.08	-0.06	-0.05
1.70	0.02	-0.05	-0.03	0.01	-0.04	0.04	-0.03	-0.02
1.80	0.01	-0.02	-0.01	0.00	-0.02	0.01	-0.01	-0.01
1.90	0.00	-0.00	-0.01	0.00	-0.01	0.00	-0.01	-0.00
2.00	0.00	-0.00	-0.00	0.00	-0.00	0.00	-0.00	-0.00

Table 7. Hough components of heating $J^{s}_{1,1}$ associated with modes (1,s,1) for $s - 1 = 1,\ldots 5$. $x = \ln(p_o/p)$

x	(1,-1,1) mW/kg Jan	Apr	Jul	Oct	(1,3,1) mW/kg Jan	Apr	Jul	Oct
	Real Part							
0.00	-0.30	0.05	0.21	-0.00	-0.33	-0.08	-0.23	-0.22
0.10	-0.17	0.15	0.24	0.02	-0.26	-0.09	-0.26	-0.28
0.20	-0.11	0.04	0.11	-0.10	-0.24	-0.20	-0.38	-0.38
0.30	-0.05	0.03	0.04	-0.09	-0.11	-0.11	-0.27	-0.29
0.40	-0.05	-0.08	-0.11	-0.11	0.03	-0.03	-0.16	-0.15
0.50	-0.03	-0.05	-0.09	-0.04	0.07	0.01	-0.09	-0.05
0.60	-0.08	-0.06	-0.08	-0.03	0.09	0.04	-0.01	0.03
0.70	-0.06	-0.02	0.00	0.07	0.23	0.19	0.16	0.30
0.80	0.04	0.01	-0.05	0.15	0.33	0.27	0.29	0.48
0.90	0.06	0.01	-0.09	0.17	0.30	0.25	0.36	0.51
1.00	-0.05	-0.09	-0.22	-0.10	0.14	0.18	0.24	0.31
1.10	-0.06	-0.18	-0.29	-0.28	0.21	0.25	0.25	0.28
1.20	0.03	-0.22	-0.41	-0.21	0.28	0.29	0.42	0.42
1.30	0.04	-0.16	-0.47	-0.12	0.20	0.26	0.37	0.37
1.40	0.02	-0.09	-0.34	-0.07	0.10	0.19	0.23	0.22
1.50	0.00	-0.00	-0.19	-0.04	0.04	0.17	0.12	0.11
1.60	0.00	0.03	-0.09	-0.03	0.02	0.12	0.05	0.05
1.70	0.00	0.01	-0.04	-0.01	0.01	0.05	0.02	0.02
1.80	0.00	0.00	-0.02	-0.01	0.00	0.02	0.01	0.01
1.90	0.00	0.00	-0.01	-0.00	0.00	0.01	0.01	0.00
2.00	0.00	-0.00	-0.00	-0.00	0.00	0.00	0.00	0.00
	Imaginary Part							
0.00	0.10	0.28	0.36	0.19	-0.28	-0.12	-0.16	-0.11
0.10	0.16	0.27	0.35	0.17	-0.25	-0.06	-0.15	-0.12
0.20	0.18	0.10	0.11	0.08	-0.20	-0.05	-0.15	-0.11
0.30	0.19	0.13	0.11	0.08	-0.24	-0.16	-0.20	-0.14
0.40	0.19	0.17	0.09	0.09	-0.26	-0.25	-0.22	-0.16
0.50	0.14	0.16	0.05	0.05	-0.18	-0.26	-0.15	-0.11
0.60	0.07	0.16	0.04	0.01	-0.12	-0.30	-0.08	-0.06
0.70	-0.03	0.18	0.05	-0.03	-0.04	-0.35	0.02	-0.02
0.80	-0.09	0.15	0.12	0.00	0.05	-0.25	0.05	-0.00
0.90	-0.11	0.13	0.12	0.01	0.10	-0.15	0.07	-0.00
1.00	-0.06	0.09	0.13	0.05	0.09	-0.08	-0.02	-0.01
1.10	-0.10	0.05	0.23	0.13	0.14	0.07	-0.03	0.01
1.20	-0.21	-0.08	0.36	0.20	0.27	0.35	-0.04	-0.01
1.30	-0.21	-0.15	0.35	0.19	0.26	0.45	-0.06	-0.04
1.40	-0.13	-0.12	0.23	0.13	0.17	0.38	-0.05	-0.04
1.50	-0.07	-0.15	0.13	0.07	0.09	0.33	-0.03	-0.02
1.60	-0.03	-0.12	0.06	0.03	0.04	0.22	-0.02	-0.01
1.70	-0.01	-0.06	0.03	0.01	0.02	0.10	-0.01	-0.00
1.80	-0.01	-0.02	0.01	0.01	0.01	0.04	-0.00	-0.00
1.90	-0.00	-0.01	0.00	0.00	0.00	0.01	-0.00	0.00
2.00	-0.00	-0.00	0.00	-0.00	0.00	0.01	0.00	0.00

Table 7. (continued)

	(1,-2,1)				(1,4,1)			
	mW/kg				mW/kg			
x	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct
	Real Part							
0.00	0.14	-0.05	-0.01	0.17	0.25	0.24	0.16	0.12
0.10	0.07	-0.08	-0.06	0.10	0.27	0.23	0.14	0.15
0.20	0.09	-0.06	-0.03	-0.03	0.32	0.21	0.14	0.17
0.30	0.09	-0.05	-0.09	-0.07	0.27	0.17	0.09	0.12
0.40	0.06	-0.06	-0.14	-0.08	0.21	0.12	0.02	0.06
0.50	0.01	-0.10	-0.08	-0.05	0.16	0.05	0.01	0.02
0.60	-0.06	-0.17	-0.01	0.02	0.12	-0.03	0.02	0.02
0.70	-0.10	-0.23	0.09	0.13	0.08	-0.14	0.03	-0.01
0.80	-0.12	-0.18	0.06	0.07	-0.06	-0.17	-0.04	-0.09
0.90	-0.18	-0.17	0.10	0.04	-0.20	-0.16	-0.06	-0.14
1.00	-0.14	-0.12	0.02	-0.09	-0.15	-0.07	-0.02	-0.07
1.10	-0.13	-0.05	-0.19	-0.24	-0.20	-0.07	-0.06	-0.08
1.20	-0.23	0.02	-0.25	-0.32	-0.46	-0.06	-0.14	-0.20
1.30	-0.21	0.12	-0.17	-0.27	-0.46	0.03	-0.12	-0.20
1.40	-0.13	0.16	-0.10	-0.17	-0.30	0.08	-0.07	-0.12
1.50	-0.07	0.21	-0.06	-0.09	-0.16	0.17	-0.04	-0.06
1.60	-0.03	0.16	-0.03	-0.05	-0.07	0.15	-0.02	-0.03
1.70	-0.01	0.07	-0.01	-0.02	-0.03	0.07	-0.01	-0.01
1.80	-0.01	0.03	-0.01	-0.01	-0.02	0.02	-0.00	-0.01
1.90	-0.00	0.01	-0.00	-0.00	-0.01	0.01	-0.00	-0.00
2.00	-0.00	0.00	-0.00	-0.00	-0.00	0.00	-0.00	-0.00
	Imaginary Part							
0.00	-0.26	-0.22	-0.44	-0.44	0.07	0.12	0.18	0.13
0.10	-0.16	-0.13	-0.25	-0.30	0.12	0.20	0.20	0.21
0.20	-0.21	-0.26	-0.36	-0.20	0.16	0.20	0.19	0.27
0.30	-0.12	-0.24	-0.33	-0.22	0.08	0.14	0.13	0.19
0.40	0.05	-0.06	-0.20	-0.13	-0.04	0.01	0.02	0.02
0.50	0.11	-0.00	-0.11	-0.06	-0.08	-0.05	-0.01	-0.04
0.60	0.15	0.01	-0.06	-0.04	-0.11	-0.12	-0.05	-0.12
0.70	0.21	0.07	-0.04	-0.01	-0.22	-0.32	-0.13	-0.37
0.80	0.17	0.16	0.02	0.11	-0.27	-0.36	-0.17	-0.44
0.90	0.15	0.17	0.13	0.15	-0.27	-0.31	-0.18	-0.41
1.00	0.09	0.12	0.30	0.22	-0.20	-0.17	-0.14	-0.24
1.10	-0.02	0.18	0.32	0.38	-0.14	-0.11	-0.17	-0.18
1.20	-0.12	0.19	0.37	0.45	-0.15	-0.02	-0.19	-0.16
1.30	-0.14	0.13	0.38	0.34	-0.13	0.05	-0.14	-0.10
1.40	-0.10	0.07	0.27	0.20	-0.08	0.06	-0.08	-0.04
1.50	-0.06	0.03	0.15	0.11	-0.04	0.04	-0.04	-0.01
1.60	-0.03	0.02	0.07	0.05	-0.02	0.02	-0.02	-0.00
1.70	-0.01	0.01	0.03	0.03	-0.01	0.01	-0.01	-0.00
1.80	-0.01	0.00	0.02	0.01	-0.00	0.01	-0.00	0.00
1.90	-0.00	0.00	0.01	0.01	-0.00	0.00	-0.00	0.00
2.00	-0.00	0.00	0.00	0.00	-0.00	0.00	-0.00	0.00

Table 7. (continued)

x	(1,-3,1) mW/kg Jan	Apr	Jul	Oct	(1,5,1) mW/kg Jan	Apr	Jul	Oct
Real Part								
0.00	0.11	0.02	-0.12	0.16	0.15	0.08	0.08	0.32
0.10	0.09	-0.02	-0.15	0.15	0.14	0.08	0.05	0.30
0.20	0.00	-0.12	-0.13	0.09	0.19	0.10	0.14	0.34
0.30	0.01	-0.10	-0.11	0.02	0.14	0.13	0.15	0.36
0.40	0.05	-0.01	-0.03	0.02	0.09	0.14	0.15	0.36
0.50	0.02	-0.05	-0.03	0.04	0.06	0.07	0.09	0.24
0.60	-0.01	-0.11	-0.04	0.08	0.01	0.00	0.02	0.13
0.70	-0.04	-0.16	-0.08	0.16	-0.03	-0.12	-0.06	-0.06
0.80	-0.06	-0.12	-0.01	0.05	-0.03	-0.16	-0.06	-0.20
0.90	-0.04	-0.13	0.04	0.03	-0.00	-0.16	-0.08	-0.27
1.00	-0.06	-0.07	0.03	-0.04	0.00	-0.09	-0.08	-0.20
1.10	-0.14	0.03	-0.00	-0.20	-0.06	-0.04	-0.04	-0.27
1.20	-0.16	0.10	0.09	-0.35	-0.06	-0.01	-0.04	-0.45
1.30	-0.12	0.11	0.18	-0.31	-0.02	0.04	-0.03	-0.42
1.40	-0.07	0.08	0.14	-0.20	-0.00	0.07	-0.02	-0.26
1.50	-0.03	0.08	0.08	-0.10	-0.00	0.10	-0.01	-0.13
1.60	-0.02	0.06	0.03	-0.05	-0.00	0.08	-0.00	-0.06
1.70	-0.01	0.03	0.01	-0.02	-0.00	0.04	-0.00	-0.03
1.80	-0.00	0.01	0.01	-0.01	-0.00	0.01	-0.00	-0.01
1.90	-0.00	0.00	0.00	-0.01	-0.00	0.00	-0.00	-0.01
2.00	-0.00	0.00	0.00	-0.00	-0.00	0.00	-0.00	-0.00
Imaginary Part								
0.00	-0.05	0.10	-0.19	-0.16	0.06	0.11	0.04	-0.03
0.10	0.01	0.09	-0.13	-0.08	0.08	0.13	0.05	-0.01
0.20	-0.10	0.04	-0.07	0.03	0.09	0.05	0.01	-0.01
0.30	-0.08	-0.00	-0.05	0.03	0.12	0.01	0.00	-0.00
0.40	-0.04	-0.01	-0.00	0.02	0.11	-0.02	0.01	0.01
0.50	0.01	-0.02	0.03	0.01	0.05	-0.00	0.01	0.00
0.60	0.04	-0.03	0.10	-0.01	-0.01	0.01	-0.02	-0.04
0.70	0.12	-0.03	0.18	-0.02	-0.18	0.02	-0.04	-0.10
0.80	0.14	-0.03	0.15	-0.02	-0.25	0.04	0.01	-0.05
0.90	0.15	-0.06	0.10	-0.07	-0.25	0.08	0.07	0.02
1.00	0.06	-0.08	0.09	0.04	-0.13	0.04	0.04	0.03
1.10	-0.06	-0.11	0.12	0.15	-0.08	-0.01	0.00	0.05
1.20	-0.12	-0.13	0.03	0.09	-0.05	0.00	0.09	0.14
1.30	-0.13	-0.08	-0.03	0.03	0.00	-0.04	0.13	0.15
1.40	-0.10	-0.05	-0.03	0.01	0.02	-0.08	0.09	0.10
1.50	-0.06	0.03	-0.02	0.00	0.02	-0.15	0.05	0.05
1.60	-0.03	0.05	-0.01	0.00	0.01	-0.13	0.02	0.03
1.70	-0.01	0.02	-0.01	0.00	0.01	-0.06	0.01	0.01
1.80	-0.01	0.01	-0.00	0.00	0.00	-0.02	0.00	0.01
1.90	-0.00	0.00	-0.00	0.00	0.00	-0.01	0.00	0.00
2.00	-0.00	0.00	-0.00	0.00	-0.00	-0.00	0.00	0.00

Table 7. (continued)

x	(1,-4,1) mW/kg Jan	Apr	Jul	Oct	(1,6,1) mW/kg Jan	Apr	Jul	Oct
Real Part								
0.00	0.15	0.09	0.23	0.37	-0.02	0.07	0.03	0.08
0.10	0.13	0.09	0.22	0.26	-0.03	0.08	0.02	0.13
0.20	0.10	-0.01	0.02	0.14	0.02	0.11	0.12	0.21
0.30	0.07	0.04	0.03	0.08	0.02	0.12	0.10	0.16
0.40	0.02	0.06	0.04	0.04	0.00	0.11	0.08	0.10
0.50	-0.01	0.05	0.02	0.01	-0.00	0.07	0.06	0.06
0.60	-0.04	0.05	-0.01	0.00	-0.01	0.05	0.05	0.03
0.70	-0.10	0.01	-0.06	-0.00	-0.04	-0.02	0.02	-0.05
0.80	-0.11	-0.03	-0.06	-0.04	-0.06	-0.09	-0.01	-0.12
0.90	-0.09	-0.06	-0.09	-0.05	-0.04	-0.13	-0.04	-0.15
1.00	-0.06	-0.03	-0.04	-0.09	-0.03	-0.11	-0.05	-0.10
1.10	-0.08	-0.03	0.03	-0.16	-0.06	-0.15	-0.09	-0.15
1.20	-0.09	-0.09	0.02	-0.22	-0.05	-0.23	-0.17	-0.26
1.30	-0.06	-0.13	-0.00	-0.18	-0.03	-0.23	-0.16	-0.24
1.40	-0.04	-0.12	0.00	-0.11	-0.02	-0.17	-0.11	-0.15
1.50	-0.02	-0.11	0.00	-0.06	-0.01	-0.14	-0.06	-0.08
1.60	-0.01	-0.07	0.00	-0.03	-0.01	-0.10	-0.03	-0.04
1.70	-0.00	-0.03	0.00	-0.01	-0.00	-0.04	-0.01	-0.02
1.80	-0.00	-0.01	0.00	-0.01	-0.00	-0.02	-0.01	-0.01
1.90	-0.00	-0.00	0.00	-0.00	-0.00	-0.01	-0.00	-0.00
2.00	-0.00	-0.00	0.00	-0.00	-0.00	-0.00	-0.00	-0.00

x	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct
Imaginary Part								
0.00	-0.02	0.09	0.05	-0.07	0.24	0.08	0.09	0.01
0.10	0.03	0.09	0.09	0.01	0.22	0.08	0.09	0.05
0.20	0.06	0.11	0.14	0.11	0.18	0.01	0.06	0.09
0.30	0.05	0.06	0.12	0.06	0.16	0.00	0.04	0.09
0.40	0.00	-0.03	0.06	-0.01	0.13	0.01	0.03	0.08
0.50	0.02	-0.06	0.05	-0.01	0.09	0.03	0.04	0.04
0.60	0.03	-0.10	0.01	-0.03	0.04	0.08	0.06	0.01
0.70	0.02	-0.15	-0.04	-0.06	-0.07	0.15	0.08	-0.06
0.80	-0.01	-0.12	-0.02	-0.04	-0.15	0.08	0.00	-0.15
0.90	-0.01	-0.09	-0.03	0.04	-0.17	0.01	-0.03	-0.25
1.00	-0.01	-0.04	-0.08	0.05	-0.13	-0.02	-0.01	-0.16
1.10	-0.07	0.00	0.01	-0.06	-0.18	-0.10	-0.10	-0.12
1.20	-0.16	0.07	0.07	-0.06	-0.28	-0.29	-0.22	-0.28
1.30	-0.16	0.14	0.01	-0.02	-0.25	-0.34	-0.22	-0.30
1.40	-0.10	0.15	-0.01	-0.01	-0.16	-0.27	-0.14	-0.20
1.50	-0.06	0.17	-0.01	-0.00	-0.08	-0.24	-0.07	-0.10
1.60	-0.03	0.12	-0.00	-0.00	-0.04	-0.16	-0.04	-0.05
1.70	-0.01	0.05	-0.00	-0.00	-0.02	-0.08	-0.02	-0.02
1.80	-0.01	0.02	0.00	-0.00	-0.01	-0.03	-0.01	-0.01
1.90	-0.00	0.01	-0.00	0.00	-0.00	-0.01	-0.00	-0.00
2.00	-0.00	0.00	-0.00	0.00	-0.00	-0.00	-0.00	-0.00

Table 7. (continued)

semi-diurnal heating.

The values obtained for the anti-symmetric components $J^2_{2,3}$, $J^2_{2,5}$ are small compared with $J^2_{2,2}$ being less than 0.7 and 0.3 mW/kg respectively. One possible explanation for the smallness of these quantities is that the effect of the seasonal movement of water vapour into the summer hemisphere is largely off-set by the decrease in the Fourier component with the longer duration of daylight in the summer hemisphere; and correspondingly in the winter hemisphere.

Components $J^s_{2,2}$ ($s \neq 2$) have been evaluated for a range of values of $|s - 2|$ and their amplitudes are found to be small (less than 15 per cent) in comparison with $J^2_{2,2}$. For $|s - 2| = 1, 2, 3$, the largest values of $J^s_{2,2}$ progressively decrease (Table 8) and for $|s - 2| = 4$ values are less than 0.1 mW/kg. For the ranges of values of n and s considered, $J^2_{2,n}$ and $J^s_{2,2}$ decrease as n and $|s - 2|$ increase more rapidly than their diurnal counterparts $J^1_{1,n}$ and $J^s_{1,1}$ (Tables 6 to 8).

8. Discussion

Formulae have been derived in § 6 for the Hough components of water vapour heating which extend previous work by taking account of cloud-related scattering properties of the atmosphere and of longitudinal variations in the relevant terrestrial data.

x	(2,1,2) mW/kg Jan	Apr	Jul	Oct	(2,3,2) mW/kg Jan	Apr	Jul	Oct
Real Part								
0.00	0.16	0.10	0.05	0.11	0.14	0.08	0.03	0.10
0.10	0.04	0.01	0.01	0.09	0.03	-0.01	0.00	0.08
0.20	0.02	-0.01	0.10	0.11	0.02	-0.02	0.10	0.10
0.30	0.04	-0.03	0.06	0.11	0.03	-0.04	0.06	0.11
0.40	0.06	-0.03	0.04	0.11	0.05	-0.05	0.04	0.12
0.50	0.03	-0.04	0.02	0.07	0.02	-0.05	0.02	0.08
0.60	-0.04	-0.07	-0.00	0.02	-0.03	-0.08	-0.00	0.02
0.70	-0.10	-0.09	-0.02	-0.07	-0.08	-0.10	-0.04	-0.07
0.80	-0.11	-0.05	-0.08	-0.14	-0.10	-0.05	-0.10	-0.14
0.90	-0.12	-0.02	-0.11	-0.16	-0.11	-0.02	-0.11	-0.16
1.00	-0.16	-0.12	-0.19	-0.22	-0.14	-0.09	-0.17	-0.19
1.10	-0.25	-0.18	-0.33	-0.37	-0.21	-0.11	-0.29	-0.33
1.20	-0.31	-0.12	-0.38	-0.41	-0.28	-0.05	-0.34	-0.39
1.30	-0.25	-0.06	-0.29	-0.30	-0.23	0.00	-0.26	-0.29
1.40	-0.15	-0.03	-0.17	-0.17	-0.14	0.01	-0.15	-0.16
1.50	-0.07	0.00	-0.09	-0.09	-0.07	0.02	-0.08	-0.08
1.60	-0.03	0.01	-0.04	-0.04	-0.03	0.02	-0.04	-0.04
1.70	-0.02	0.00	-0.02	-0.02	-0.01	0.01	-0.02	-0.02
1.80	-0.01	-0.00	-0.01	-0.01	-0.01	0.00	-0.01	-0.01
1.90	-0.00	-0.00	-0.01	-0.01	-0.00	-0.00	-0.01	-0.01
2.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
Imaginary Part								
0.00	0.08	-0.07	0.04	-0.10	-0.07	0.08	-0.04	0.09
0.10	0.17	0.06	0.11	0.01	-0.15	-0.03	-0.10	0.00
0.20	0.19	0.10	0.17	0.09	-0.17	-0.07	-0.15	-0.07
0.30	0.14	0.11	0.17	0.09	-0.12	-0.08	-0.16	-0.07
0.40	0.04	0.06	0.13	0.04	-0.04	-0.05	-0.13	-0.04
0.50	0.04	0.05	0.12	0.06	-0.04	-0.05	-0.11	-0.06
0.60	0.03	0.03	0.13	0.08	-0.03	-0.05	-0.12	-0.07
0.70	-0.00	-0.01	0.09	0.07	-0.00	-0.02	-0.08	-0.06
0.80	-0.08	-0.09	-0.08	-0.02	0.08	0.07	0.09	0.02
0.90	-0.13	-0.16	-0.21	-0.07	0.14	0.14	0.21	0.08
1.00	-0.10	-0.09	-0.24	-0.03	0.10	0.07	0.22	0.03
1.10	-0.14	-0.11	-0.36	-0.04	0.14	0.10	0.32	0.03
1.20	-0.27	-0.24	-0.59	-0.15	0.28	0.24	0.55	0.14
1.30	-0.26	-0.21	-0.56	-0.16	0.27	0.21	0.52	0.15
1.40	-0.16	-0.12	-0.35	-0.09	0.17	0.11	0.33	0.09
1.50	-0.08	-0.02	-0.17	-0.04	0.08	0.01	0.16	0.04
1.60	-0.04	0.02	-0.08	-0.02	0.04	-0.02	0.07	0.02
1.70	-0.02	0.01	-0.03	-0.00	0.02	-0.01	0.03	0.00
1.80	-0.01	0.01	-0.01	-0.00	0.01	-0.01	0.01	0.00
1.90	-0.00	0.00	-0.01	0.00	0.00	-0.00	0.01	-0.00
2.00	-0.00	0.00	-0.00	0.00	0.00	-0.00	0.00	-0.00

Table 8. Hough components of heating $J^{s}_{2,2}$ associated with modes (2,s,2) for s − 2 = 1, 2, 3. $x = \ln(p_0/p)$

x	(2,0,2) mW/kg				(2,4,2) mW/kg			
	Jan	Apr	Jul	Oct	Jan	Apr	Jul	Oct
	Real Part							
0.00	0.11	0.09	0.21	0.17	0.11	0.05	0.18	0.13
0.10	0.13	0.15	0.24	0.23	0.10	0.08	0.20	0.17
0.20	0.14	0.14	0.24	0.21	0.10	0.12	0.23	0.19
0.30	0.09	0.10	0.16	0.15	0.05	0.07	0.14	0.14
0.40	-0.03	-0.01	0.03	0.03	-0.04	-0.01	0.04	0.04
0.50	-0.04	-0.02	-0.01	0.01	-0.05	-0.02	-0.00	0.01
0.60	-0.07	-0.04	-0.05	-0.03	-0.07	-0.04	-0.04	-0.03
0.70	-0.13	-0.11	-0.13	-0.13	-0.14	-0.11	-0.12	-0.16
0.80	-0.15	-0.14	-0.20	-0.20	-0.17	-0.15	-0.20	-0.24
0.90	-0.12	-0.13	-0.25	-0.23	-0.14	-0.14	-0.25	-0.26
1.00	-0.10	-0.14	-0.23	-0.26	-0.10	-0.14	-0.22	-0.23
1.10	-0.16	-0.23	-0.28	-0.33	-0.15	-0.22	-0.26	-0.28
1.20	-0.17	-0.27	-0.41	-0.38	-0.17	-0.25	-0.38	-0.34
1.30	-0.11	-0.22	-0.39	-0.29	-0.11	-0.21	-0.36	-0.27
1.40	-0.05	-0.14	-0.24	-0.17	-0.06	-0.14	-0.23	-0.16
1.50	-0.03	-0.09	-0.12	-0.08	-0.03	-0.09	-0.12	-0.08
1.60	-0.01	-0.05	-0.06	-0.04	-0.01	-0.06	-0.06	-0.04
1.70	-0.01	-0.02	-0.03	-0.02	-0.01	-0.02	-0.03	-0.02
1.80	-0.00	-0.01	-0.01	-0.01	-0.00	-0.01	-0.01	-0.01
1.90	-0.00	-0.00	-0.01	-0.00	-0.00	-0.00	-0.01	-0.00
2.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00
	Imaginary Part							
0.00	-0.12	0.05	0.05	0.00	0.14	-0.02	-0.01	0.01
0.10	-0.05	0.07	0.04	-0.00	0.08	-0.05	-0.01	0.02
0.20	-0.02	-0.02	-0.05	-0.06	0.05	0.00	0.05	0.04
0.30	-0.03	-0.05	-0.08	-0.07	0.06	0.05	0.08	0.05
0.40	-0.06	-0.08	-0.11	-0.06	0.07	0.09	0.10	0.06
0.50	-0.03	-0.08	-0.07	-0.04	0.04	0.09	0.07	0.03
0.60	-0.02	-0.09	-0.02	-0.01	0.02	0.11	0.03	0.02
0.70	-0.02	-0.10	0.07	0.01	0.01	0.14	-0.05	0.00
0.80	0.01	-0.05	0.10	0.03	-0.03	0.08	-0.08	-0.02
0.90	0.03	-0.00	0.11	0.03	-0.05	0.04	-0.09	-0.03
1.00	0.06	0.03	0.06	0.07	-0.06	0.01	-0.04	-0.04
1.10	0.10	0.11	0.09	0.14	-0.09	-0.07	-0.05	-0.08
1.20	0.14	0.22	0.14	0.16	-0.15	-0.21	-0.09	-0.10
1.30	0.13	0.23	0.11	0.12	-0.15	-0.25	-0.08	-0.08
1.40	0.09	0.18	0.06	0.07	-0.10	-0.19	-0.05	-0.05
1.50	0.05	0.13	0.03	0.04	-0.06	-0.15	-0.03	-0.03
1.60	0.03	0.08	0.01	0.02	-0.03	-0.09	-0.01	-0.02
1.70	0.02	0.03	0.01	0.01	-0.02	-0.04	-0.01	-0.01
1.80	0.01	0.01	0.00	0.01	-0.01	-0.02	-0.00	-0.01
1.90	0.01	0.01	0.00	0.00	-0.01	-0.01	-0.00	-0.00
2.00	0.00	0.00	0.00	0.00	-0.00	-0.00	-0.00	-0.00

Table 8. (continued)

x	(2,-1,2) mW/kg Jan	Apr	Jul	Oct	(2,5,2) mW/kg Jan	Apr	Jul	Oct
Real Part								
0.00	-0.10	-0.03	-0.06	-0.08	-0.09	-0.13	-0.07	-0.02
0.10	-0.09	-0.02	-0.04	-0.08	-0.12	-0.13	-0.06	-0.05
0.20	-0.10	-0.03	-0.03	-0.02	-0.14	-0.11	-0.06	-0.09
0.30	-0.09	-0.04	-0.01	0.02	-0.11	-0.08	-0.05	-0.07
0.40	-0.04	-0.04	0.02	0.03	-0.08	-0.05	-0.03	-0.04
0.50	-0.00	0.00	0.02	0.03	-0.07	-0.03	-0.01	-0.01
0.60	0.03	0.06	0.01	0.00	-0.06	-0.00	-0.00	0.00
0.70	0.05	0.11	-0.00	-0.04	-0.04	0.04	0.02	0.04
0.80	0.07	0.10	0.01	-0.00	0.02	0.06	0.04	0.07
0.90	0.11	0.10	0.01	0.02	0.08	0.06	0.06	0.09
1.00	0.08	0.07	0.04	0.04	0.06	0.03	0.02	0.02
1.10	0.06	0.04	0.09	0.06	0.10	0.05	0.01	-0.00
1.20	0.10	0.02	0.10	0.09	0.21	0.07	0.04	0.05
1.30	0.10	-0.01	0.07	0.08	0.20	0.04	0.05	0.06
1.40	0.06	-0.02	0.04	0.05	0.13	0.02	0.04	0.05
1.50	0.03	-0.04	0.02	0.03	0.07	-0.03	0.02	0.03
1.60	0.01	-0.03	0.01	0.01	0.03	-0.03	0.01	0.01
1.70	0.01	-0.01	0.01	0.01	0.02	-0.01	0.01	0.01
1.80	0.00	-0.00	0.00	0.00	0.01	-0.00	0.00	0.00
1.90	0.00	-0.00	0.00	0.00	0.00	0.00	0.00	0.00
2.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Imaginary Part								
0.00	0.08	0.10	0.10	0.12	0.04	-0.00	0.01	0.05
0.10	0.07	0.09	0.05	0.09	-0.02	-0.07	-0.04	-0.03
0.20	0.09	0.10	0.05	0.07	-0.03	-0.04	-0.03	-0.09
0.30	0.06	0.08	0.06	0.08	-0.00	-0.02	-0.01	-0.05
0.40	-0.03	-0.01	0.01	0.03	0.01	0.00	0.02	0.01
0.50	-0.05	-0.02	0.01	0.01	0.02	0.02	0.02	0.02
0.60	-0.06	-0.05	0.01	-0.01	0.02	0.05	0.02	0.05
0.70	-0.08	-0.11	0.01	-0.07	0.06	0.14	0.06	0.17
0.80	-0.09	-0.12	-0.02	-0.10	0.08	0.14	0.06	0.18
0.90	-0.09	-0.10	-0.05	-0.09	0.09	0.11	0.04	0.15
1.00	-0.05	-0.05	-0.09	-0.07	0.06	0.05	-0.01	0.05
1.10	-0.01	-0.02	-0.10	-0.07	0.06	0.01	0.00	-0.02
1.20	-0.01	0.01	-0.10	-0.07	0.08	-0.04	-0.00	-0.04
1.30	-0.02	0.02	-0.09	-0.04	0.08	-0.06	-0.03	-0.05
1.40	-0.01	0.02	-0.05	-0.02	0.04	-0.05	-0.04	-0.04
1.50	-0.01	0.01	-0.03	-0.01	0.02	-0.03	-0.03	-0.02
1.60	-0.00	0.00	-0.01	-0.00	0.01	-0.01	-0.02	-0.01
1.70	-0.00	0.00	-0.01	-0.00	0.00	-0.01	-0.01	-0.01
1.80	-0.00	-0.00	-0.00	-0.00	0.00	-0.00	-0.00	-0.00
1.90	-0.00	-0.00	-0.00	-0.00	0.00	-0.00	-0.00	-0.00
2.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00	-0.00

Table 8. (continued)

Solar radiation fluxes in a cloudy atmosphere depend in general on the microphysical properties of cloud particles and their spatial distributions. For practical reasons a comparatively simple physical model has been adopted in which the atmospheric column at any overcast location is treated as a scattering medium by a two-stream approximation of radiative transfer with two scattering parameters, f the fraction of forward scattered radiation in a scattering event and σ the scattering coefficient, both of which are taken to be independent of height and global position. The extent to which the heating rates obtained with $f = 0.925$ and $\sigma = 40\ cm^{-1}$ approximate mean monthly conditions (evaluated here for January, April, July and October) cannot be stated; but the curves in Figs. 3 and 4 indicate wide limits within which choices of f and σ do not seriously affect the results obtained. Greater uncertainties appear to arise from the choice of water vapour absorption coefficients (Fig. 5); and maximum heating rates are calculated here which are lower by roughly 30 per cent than those predicted by certain alternative sets of coefficients.

The omission of cloud-layer structure from the analysis is a source of uncertainty which has not been investigated. Cloud-base heights would be expected to have a relatively small effect on heating profiles compared with cloud-top

heights as radiation fluxes and heating rates at lower cloud levels are much reduced by a deep layer of overlying cloud. Heights of cloud tops affect the heating profile through enhanced radiational fluxes within and above the upper cloud region. By relating scattering to water vapour density in cloud-covered areas a spatial distribution of scattering properties is set up which roughly approximates that of large cloud systems in that scattering decreases rapidly in the upper troposphere and extends over greater depths in high humidity areas at low latitudes (Fig. 6).

Contributions from clear-sky fractions and cloudy-sky fractions are given respectively by the first and second terms in (6.10) and are compared in Figs. 6 and 7 which illustrate the effect of clouds in reducing heating in the lower troposphere and increasing it at greater heights. When clear-sky and cloudy-sky fractions are combined according to the adopted global models of cloud amounts, diurnal and semi-diurnal Hough components of heating $J^1_{1,1}$ and $J^2_{2,2}$ are nearly doubled at 8 km by the presence of cloud while values near the surface are approximately halved (Figs. 8 and 11). Heating profiles of other modes show generally similar effects due to the introduction of scattering (Figs. 9 and 10).

For symmetric modes heating components show a small seasonal modulation although phases are not necessarily the

same at all heights (Figs. 8, 9 and 11). October and April values are generally greater than January and July values, which is to be expected as the peak low-latitude water vapour densities and the sub-solar point are then closer to the equator than in January and July and a closer correspondence is set up between the latitudinal profile of heating and that of the Hough function. July values are generally slightly less than January values and a factor that contributes 7 per cent of this difference is the changing Sun-Earth distance.

For the diurnal anti-symmetric mode $J^1_{1,-1}$ (Fig. 10), January and July values are considerably greater than April and October values which is to be expected as the heating asymmetry increases with both the magnitude of solar declination and the movement of water vapour into the summer hemisphere. The slightly greater values at many heights in July than January would appear to indicate that for this particular mode the effect of the changing Sun-Earth distance is more than counterbalanced by the greater movement of water vapour into the summer hemisphere in July than January, an effect which is notable at Asian monsoon longitudes. For April and October, solar declinations of $\pm 9^{\circ}$ give rise to small anti-symmetric components (Fig. 10). With semi-diurnal modes, however, Fourier time components are greater in the winter than the summer hemisphere and no enhanced asymmetry

in heating arises with the meridional movement of water vapour into the summer hemisphere: the January and July values for $J^2_{2,3}$, $J^2_{2,5}$ are of the same order of magnitude as those in April and October being small compared with $J^2_{2,2}$ and less than 0.7 and 0.3 mW/kg respectively.

Longitudinal variations in terrestrial properties give rise to non-migrating modes ($m \neq s$) and a preliminary investigation has been undertaken of Hough components of heating for a range of longitudinal wave numbers s adjacent to the value of m (= 1, 2). Such components are found to be small (less than 15 per cent) compared with the corresponding migrating components $J^1_{1,1}$ and $J^2_{2,2}$ (Tables 7 and 8).

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REFERENCES

CHAPMAN, S. and LINDZEN, R.S. (1970) Atmospheric tides: thermal and gravitational. Dordrecht, Holland, D. Reidel Publishing Co.

CLAPP, P.F. (1964) Mon. Wea. Rev. 92, 495-507.

FORBES, J.M. and GARRETT, H.B. (1978) Geophys. Res. Lett. 5, 1013-1016.

GROVES, G.V. (1977) J. Brit. Interplan. Soc. 30, 32-36.

HARRIES, J.E. (1976) Rev. Geophys. Space Phys. 14, 565-575.

HOUGHTON, J.T. (1977) The Physics of Atmospheres, C.U.P.

HOWARD, J.N., BURCH, D.E. and WILLIAMS, D. (1956) J. Opt. Soc. Amer. 46, 186-190, 237-241, 242-245, 334-338,452-455.

HYSON, P. (1978) Quart. J. R. Met. Soc. 104, 225-228.

KERSCHGENS, M., RASCHKE, E. and REUTER, U. (1976) Beitr. Phys. Atmos. 49, 81-97.

LACIS, A.A. and HANSEN, J.E. (1974) J. Atmos. Sci. 31, 118-133.

LINDZEN, R.S. (1967) Quart. J. R. Met. Soc. 93, 18-42.

LINDZEN, R.S. and HONG, S-S. (1974) J. Atmos. Sci. 31, 1421-1446.

LONDON, J. and PARK, J.H. (1974) Can. J. Chem. 52, 1599-1615.

MANABE, S. and MÖLLER, F. (1961) Mon. Wea. Rev. 89, 503-532.

McDONALD, J.E. (1960) J. Met. 17, 319-328.

MASTENBROOK, H.J. (1971) J. Atmos. Sci. 28, 1495-1501.

MOSKALENKO, N.I. and GOLUBITSKIY, B.M. (1968) Atm. and Ocean Phys., 4, 346-359.

NEWELL, R.E., KIDSON, J.W., VINCENT, D.G. and BOER, G.J. (1972) The General Circulation of the Tropical Atmosphere and Interactions with Extratropical Latitudes, Volume I, The M.I.T. Press.

SIEBERT, M. (1961) Adv. Geophys. 7, 105-182.

SOMERVILLE, R.C.J., STONE, P.H., HALEM, M., HANSEN, J. E., HOGAN, J.S., DRUYAN, L.M., RUSSELL, G., LACIS, A.A., QUIRK, W.J. and TENENBAUM, J. (1974) J. Atmos. Sci. 31, 84-117.

THEKAEKARA, M.P. (1973) Solar Energy 14, 109-127.

TIEDTKE, M. and GELEYN, J.F. (1975) Beitr. Phys. Atmos. 48, 255-277.

WELCH, R., GELEYN, J.F., ZDUNKOWSKI, W. and KORB, G. (1976) Beitr. Phys. Atmos. 49, 128-146.

YAMAMOTO, G. (1962) J. Atmos. Sci. 19, 182-188.

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